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14. ABSTRACT
This TOP prescribes procedure and guidance for testing tires individually in the laboratory and on vehicles. Topics covered include tire storage, test preparation, mounting and dismounting, inspections, break-in, and test analysis. Test types include force and moment, rolling resistance, steer frequency response, load-deflection curves, characteristics, endurance, and several on-vehicle tests.

15. SUBJECT TERMS
tire test rig   force and moment   rolling resistance   steer frequency response   endurance
CTIS   traction   mobility   performance   tire, wheel, and rim

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-704A — 15 December 2015
DTIC AD No.

TIRES

* This TOP supersedes TOP 02-2-704, Tires, dated 23 January 1976.

Approved for public release; distribution is unlimited.

1. SCOPE.

1.1 Purpose.

This Test Operating Procedure (TOP) describes the general procedures for testing pneumatic tires used on tactical wheeled vehicles. The procedures described apply to original equipment and new replacement tires. This document also describes vehicle and component level tests that will be used to measure and analyze tire and vehicle related performance. The mission profile of the vehicle helps determine which of these tests are required and should be selected. Therefore, all of the tests included in this document are not required for each tire. The details of every individual test are not included in this TOP. Specific test procedures are referenced as needed and should be reviewed to fully understand the individual test conditions, instrumentation requirements, data presentation, and analysis techniques. This TOP does not address tire testing in cold region conditions.

1.2 Background.

a. The successful mobility of a tactical wheeled vehicle depends directly on the capability of its tires to endure high-speed, high-load operation, provide adequate traction and stability, operate at reduced inflation pressures, and exhibit sufficient runflat ability to evacuate from dangerous conditions. Tires are the only vehicle components that make contact with the ground. They are complicated, nonlinear components that must provide the required performance in all environmental and operational conditions[1**].

b. As a vehicle component, tire selection has a significant influence on performance attributes including mobility, ride quality, handling, braking, and fuel economy. Military specific performance including central tire inflation systems (CTIS) and runflat performance require specialized testing. Understanding the residual performance of battle damaged vehicles and tires are critical for Soldier safety.

2. FACILITIES AND INSTRUMENTATION.

2.1 Calibration.

a. All measuring tools and instrumentation will be calibrated against a higher order standard at periodic intervals not to exceed twelve months. Records, showing the calibration traceability to the National Institute of Standards and Technology (NIST), will be maintained for all measuring and test equipment.

b. All measuring and test equipment and measuring standards will be labeled with the following information:

(1) Date of calibration.

** Superscript numbers correspond to Appendix C, References.

(2) Date of next scheduled calibration.

(3) Name of the organization and technician who calibrated the equipment.

c. A written calibration report will be provided that includes as a minimum the following information for all measurement and test equipment:

(1) Type of equipment, manufacturer, model number, etc.

(2) Measurement range.

(3) Accuracy.

(4) Calibration interval.

(5) Type of standard used to calibrate the equipment (calibration traceability of the standard must be evident).

2.2 Measurement Tools.

Item	Requirement
Steel tape	± 0.5 millimeter (mm) (0.02 inch (in.) or better accuracy
Pi-tape (diameter measuring)	± 0.3 mm (0.01 in.) up to 3600 mm (142 in.)
Calipers	± 0.5 mm (0.02 in.) or better accuracy
Depth gauge	± 0.1 mm (0.004 in.) or better accuracy
Platform scales	[a]capable of weighing the tire or wheel to an accuracy of ± 0.5% of the scale's range or better

[a] To obtain measurements with good accuracy and resolution, measurement of the lightest tire or wheel should use at least 10% of the scale's range.

2.3 Instrumentation.

Devices for Measuring	Range, Accuracy, and Resolution
Velocity	161 kilometers per hour (km/hr) (100 miles per hour (mph)) range; 0.1 km/hr (0.1 mph) or better accuracy; 0.01 km/hr (0.01 mph) resolution

Devices for Measuring	Range, Accuracy, and Resolution
Force (rolling resistance) tire load	± 20 Newtons (N) (± 4 pounds force (lbf)) accuracy for light truck tires and ± 30 N (± 6 lbf) for highway truck and bus tires
Force, spindle	± 0.5 N (± 0.1 lbf) accuracy for light truck tires and ± 1.0 N (± 0.2 lbf) for highway truck and bus tires
Temperature, general	Accuracy of ± 0.5 Celsius (C) (± 1.0 Fahrenheit (F))
Angle	Accuracy of 0.1 degree minimum
Tire Deflection	Accuracy of 0.5 mm (0.020 in.) minimum
Tire temperature	[a]See note.
Pressure	[b]See note.

[a] Types of tire temperature measurement include thermocouple (type T or K) probes inserted into the tire tread and carcass, contained air temperature, and measurement of tread (surface) temperature.

Tread and Carcass. A small diameter (typically 3 mm or less) probe is inserted into the tire at either the belt edge or the bead area. Measurement areas in the tread should be carefully predrilled to limit block distortion when the probe is inserted. Tread (surface) measurements should be taken at least 3 mm below the surface. Repetitive measurements should be taken quickly and in the same order. Type T thermocouples have a range of -200 to 350 °C (-328 to 662 °F) with an error of measurement of 1 °C (2 °F) or 0.75%, whichever is greater. Type K thermocouples have a range of -200 to 1250 °C (-328 to 2282 °F) with an error of measurement of 2.2 °C (4 °F) or 0.75%, whichever is greater. X-ray equipment may be used to verify proper thermocouple placement.

Contained air temperature. The contained air temperature method uses thermistors fixed to the inside profile of the tire or the rim. Temperature measurements can be affected by the mounting choice. If the sensor is attached to the rim, it will pick up heat from the wheel and attachment to the tire interior will measure heat from the casing.

Tread surface temperature. Tread (surface) infrared temperature can be inconsistent since the measurements are typically performed using hand held systems. Ambient temperature measurement devices should have the following characteristics: 0 to 46 °C (32 to 115 °F) range with a 0.2 °C (0.5 °F) or better accuracy and a resolution of measurement of 1 °C (2 °F).

[b]Tire pressure inflation measurement:

Tire inflation pressure (handheld units): 1 kilopascal (kPa) (0.1 pounds per square inch (psi)) for light truck tires and 1.5 kPa (0.2 psi) for highway truck and bus tires.

Tire Pressure Monitoring System (wireless) with a range of 0 to 896 kPa (0 to 130 psi) and a resolution of 0.1 kPa (0.02 psi).

2.4 Facilities and Specialized Equipment.

2.4.1 Tire Test Rig (TTR).

The tire test rig shown in Figure 1 is co-located with the Roadway Simulator (RWS) at the U.S. Army Aberdeen Test Center (ATC). It is used for measuring tire performance parameters at all tactical wheeled vehicle weights and cornering conditions that support computer modeling, performance, and durability testing. The TTR utilizes one of the RWS Flat-Trac units, manufactured by MTS Systems Corporation***, to roll the tire and provide vertical load and lateral slip, while a stationary fixture built by ATC is used to constrain the tire in all degrees of freedom, except rolling. The TTR is capable of rotating tires at ground speeds up to 257 km/hr (160 mph), producing vertical loads in excess of 75 kilonewtons (kN) (17,000 lbf) and introducing up to 16 degrees of lateral slip. The TTR uses the RWS data acquisition system to measure the system commands and responses, as well as data specific to the tire test. A wheel force transducer (described below) is used to measure all six tire loads (Fx, Fy, Fz, Mx, My, and Mz) at the spindle or ground location as defined in Section 4.1.

Figure 1. ATC Tire Test Rig.

*** The use of brand names does not constitute endorsement by the Army or any other agency of the Federal Government, nor does it imply that it is best suited for its intended application.

2.4.2 Spinning Wheel Integrated Force Transducer (SWIFT).

The SWIFT measures the three forces and three moments at the transducer center. The SWIFT measurement system transforms the measured rotating wheel loads to non-rotating axle loads in real time. Additional post processing geometric transformations are performed to determine the forces and moments at the tire contact patch. Force and moment data from the rotating transducer provide important performance information that can be utilized in many tire and vehicle applications to include tire characterization, tread wear, rolling resistance, noise, tire-suspension interaction, and vibration analysis. It can be used to measure spindle reactions when mounted on the vehicle, or it can be mounted on the tire test rig to enhance the force and moment measurement capabilities. The high stiffness and natural frequency of the SWIFT, combined with the excellent resolution make it ideal for tire and wheel testing. Table 1 presents the performance characteristics of the ATC owned transducers.

TABLE 1. ATC WHEEL FORCE TRANSDUCERS

MAXIMUM CALIBRATED LOAD/RATINGS	SWIFT 40 (4 EACH)	SWIFT 50 (4 EACH)
Longitudinal force, F_x, kN (lb)	40 (8,992)	220 (49,458)
Lateral force, F_y, kN (lb)	30 (6,744)	100 (22,481)
Vertical force, F_z, kN (lb)	40 (8,992)	220 (49,458)
Overturning moment, M_x, kN-m (in-lb)	9 (79,657)	50 (442,537)
Rolling resistance moment, M_y, kN-m (in-lb)	13 (115,060)	50 (442,537)
Aligning moment, M_z, kN-m (in-lb)	9 (79,657)	50 (442,537)
Maximum usable speed, rpm	2,200	
Shock resistance, each axis	50 g	
Force nonlinearity, % of full scale	1	
Moment nonlinearity, % of full scale	1	

2.4.3 Off-Road Test Course Requirements.

a. The test area for the bead unseating test is sand (preferred) or sandy-loam (SP or SM as determined by Unified Soil Classification System (USCS)). The depth of the material should be at least 750 mm (30 in.), tilled to at least 200 mm (8 in.), and dried to a moisture content of less than 2.0% in the top 75 mm (3 in.). The cone index (CI) at the 75 mm (3 in.) depth should not exceed 100.

b. The cone index is measured using a Corps of Engineers cone penetrometer. The cone penetrometer consists of a 30-degree cone with a 0.5 in.^{2} base area, an 18-in. extension rod, a proving ring, a dial indicator, and a handle. The amount of force required to move the cone slowly through a given soil is indicated on the dial inside the proving ring. The force is a dimensionless index of the shearing resistance of the soil and is called the cone index of the soil

in that plane. The range of the dial is a 150-pound load and is marked 0-300 psi since the cone base is 0.5 in.^{2}. Field Manual (FM) 5-340[2] covers the calibration and use of the cone penetrometer.

c. Soil moisture content is measured using either the calcium-carbide-gas pressure method (American Association of State Highway and Transportation Officials (AASHTO) T217-1986[3]) or the methods described in American Society for Testing and Materials (ASTM) D2216-10[4]. Data are reported to the nearest 1%.

2.4.4 Paved Test Course Requirements.

a. Vehicle performance tests requiring a paved test surface are conducted on a 3.7-meter (m) (12-feet (ft)) wide level, straight roadway having a dry peak friction coefficient (pfc) of 0.9. The peak friction coefficient is measured annually using an ASTM E1136 standard reference test tire in accordance with ASTM Method E1337-90[5].

b. The test surface should be a uniform hard surface that is free of contaminants and has a gradient of not more than 1% in any direction. Ideally, the test course should be planar and have no undulations. For a standard test condition, a smooth, dry asphalt or concrete paved surface is recommended.

3. REQUIRED TEST CONDITIONS.

3.1 Preparation for Testing.

3.1.1 Tire Storage[6].

a. Tire tread and side walls are constructed from compounds that resist deterioration caused by sunlight, ozone, and extreme temperatures. Stored tires should be protected against these and other potentially damaging conditions. Store tires in an area that is clean, cool, dark, and well ventilated, but with a minimum of circulating air. Cool storage does not have any adverse effect on rubber products.

b. Avoid areas that are wet, humid, oily, greasy, or in direct sunlight. Do not store tires in the same area as an electric motor or other ozone-generating sources. If there is a question, check the ozone level to insure it does not exceed 0.08 parts per million (ppm). Do not store tires directly on black asphalt or other heat-absorbent surfaces. Avoid storage adjacent to highly reflective surfaces. As a rule, tires should be stored in the upright position to prevent distortion. If it is necessary to store tires in a horizontal position, be sure to stack passenger car and light truck radial tires no higher than 0.9 m (3 ft) and radial truck tires no higher than 1.4 m (4.5 ft). When storing tires that have been inflated, deflate them to 50% of the normal pressure. Keep valve caps in place.

3.1.2 Tire and Rim Preparation.

Tires should be inspected for punctures, damage, and manufacturing defects that would prevent their use as test items. X-ray apparatus, if available, may be useful to identify manufacturer defects. Photographs, when taken should be in color with a macro lens. A sufficient quantity of photographs should be taken to supplement any field notes. The tires are mounted on rim/wheels specified in the Tire and Rim Association Inc. (TRA) Yearbook, and/or Military Supplement and/or Engineering Design Information[7], or European Tyre and Rim Technical Organization (ETRTO) Standards Manual[8] for the size being tested, unless the military specification requires a rim/wheel that differs from the TRA Military Supplement Recommendations. Rims must be compatible with the pressure and the test vehicle. Rims should also be inspected for any defects that could damage the tires during mounting. The tires are mounted on their rims in such a way that the tire identification number (TIN) and other identifying data are conspicuous when installed on the vehicle. After the tires are mounted they are inflated to the pressure specified by the manufacturer or vehicle manual, whichever is higher, and left standing for a period of 24 hours at room temperature, after which pressures are rechecked.

3.1.3 Tire Marking and Identification.

a. Each tire should be marked so that it can be distinguished from other tires in the test series. After mounting, the tire and rim will be marked with three sets of radial lines from bead-to-bead. These lines are spaced every 120 degrees circumferentially around the spin axis with the 0 degree line located at the Department of Transportation (DOT) serial number on tires with a DOT serial number. In the case of tires without a DOT serial number a 0 degree location agreeable to the test sponsor will be selected. Starting at the tire serial number location, mark each location sequentially, 1 through 6, going in a clockwise direction around the tire, with the serial number facing out. Mark the intended tire rotational direction for testing, noting that some tires are unidirectional. The following information should also be recorded for each tire.

(1) Manufacturer.

(2) Tire brand.

(3) Tire size and type.

(4) Maximum tire load rating (if load rating for dual tire installation is given, record both), kilogram (kg) (pound (lb)).

(5) Tire speed rating.

(6) Maximum inflation pressure, kPa (psi).

(7) DOT serial number.

(8) Tire descriptor; the following are the most common.

(a) Regular tread tire.

(b) All-terrain tire.

(c) Mud and snow tire.

(d) Snow tread tire.

(e) On/off-road tire.

(f) Steer axle position only.

(g) Drive axle position only.

(h) All position.

(i) Trailer position only.

(9) Tire ply rating: An index of (tire) strength that does not necessarily represent the number of cord plies in the tire. It identifies a given tire with its maximum recommended load when used in a specific type of service.

b. Branding is also an acceptable method of marking tires as long as the following guidelines are followed. The following limits apply when branding tires using equipment without accurate temperature control or which may exceed surface temperatures of 240 °C (465 °F).

(1) The brand temperature and maximum depth should not exceed:

(a) 300 °C (570 °F) and 0.4 mm (1/64 in.)

(b) 250 °C (480 °F) and 0.8 mm (1/32 in.).

(2) The tires should only be branded in areas specifically designated on the tire as "BRAND TIRE HERE". Cold branding is defined as marking equipment generating a tire surface temperature below 250 °C (480 °F). Cold branding guidelines are defined below.

(a) Maximum temperature: 240 °C (465 °F).

(b) Maximum contact pressure: 690 kPa (100 psi).

(c) Time of contact: Not To Exceed (NTE) 1 minute.

(d) Character Height: NTE 25 mm (1 in.).

(e) Character Depth: NTE 1.0 mm (0.040 in.).

3.1.4 Tire Mounting and Dismounting.

a. During tire and rim preparation and at each tire replacement or repair during the course of testing, observations should be made with respect to the degree of difficulty encountered when mounting, dismounting, handling, or repairing a tire. The time to mount, dismount, or repair a tire; the difficulties encountered; and the suitability of special tools (if applicable) should be recorded to support the maintenance analysis.

b. The following guidelines should be followed when mounting and dismounting tires and wheels. Additional information regarding the safety precautions for mounting and demounting tube type truck/bus tires are available through the United States Department of Transportation, National Highway Traffic Safety Administration (NHTSA), Washington, DC 20590, www.nhtsa.dot.gov[9].

(1) A non-water base commercial bead lubricant should be used to lubricate the tire since water in the tire can cause excessive rim corrosion problems. Lubricants that contain a rust inhibitor should be used, if available. Avoid the use of excessive lubricant. Never use anti-freeze, silicones, or petroleum based lubricants. Always use a lubricant when mounting radial truck tires to ensure proper bead seating and to prevent eccentric mounting. Check the distance between the tire “GG” ring (see Appendix A Glossary) and the top of the rim or wheel flange to insure it is uniform all around the tire. The flexible sidewall of a radial tire makes the use of lubricant in the bead area more critical than for bias ply tires that have stiffer sidewalls.

(2) To prepare the tire, clean and dry the inside with an air hose. Inspect the interior for loose material. Dust the inside of the tire lightly with dry soapstone to prevent the tube, if used, from sticking to the tire. Do not let soapstone accumulate in the tire. Inspect and clean the tire beads to remove corrosion or residual rubber. Wipe the beads clean.

(3) To prepare the rim, remove any dirt, surface rust, scale and rubber build up. Repaint the rim if needed. Clean the tire seat areas thoroughly to insure proper fitment of the tire and to eliminate potential air leaks in tubeless assemblies. Remove any burrs or nicks on the tire side of the rim. These may damage the tire during mounting or in service. Clean all dirt and rust from the lock ring and gutter. This is critical to secure the lock ring in its proper position. Verify that the rim type is compatible with the tire type and size.

(4) Always install a new radial tube and a new radial flap in a new tire, if used. Use only tubes designated for radials and make sure the proper size tube and flap are used. Precautions must be taken when mounting used flaps, or damage to the tire and tube will result. New flaps can be used with any one of several different tire and rim sizes as recommended. But, once used, the flap must be remounted in the same size tire and on the same size rim from which it was removed. Always use a flap of adequate width to prevent tube pinching. As a precaution against flap failure, mark the tire and rim size on the flap at the time of removal.

(5) The plastic cap that comes on a new tube is not a valve cap and will eventually leak air at high inflation pressure used in truck tires. Its only purpose is to keep dust and dirt out

of the valve stem during shipment, protect the threads of the valve stem, and shield the folded tube against abrasion by the threads. A metal valve cap contains a rubber gasket that provides an air seal. Always replace the plastic cap with a metal cap or a self-sealing nylon cap.

(6) Bend the valve stem to its proper position. If it is left flat and touching the rim, the valve cap will be difficult to remove and accurate on-vehicle air pressure checks will be difficult. Make sure the valve stem does not contact the brake drum. Heat from the drum will be conducted along the valve stem to the tube/flap area around the stem base and cause decomposition of the rubber. This will lead to a premature tube failure.

(7) Insert the tube into the tire and partially inflate it to round out the tube. Apply rubber lubricant to the inside and outside surfaces of both beads and to the portion of the tube that appears between the beads. Do not allow lubricant to run down into the tire.

(8) After mounting and before inflating the tire, inspect all components of multi-piece rims to make sure they are in place. Insure that tires are properly mounted and seated on the rims by checking the distance between the tire GG ring and the rim flange. The rim flange must be concentric with the GG ring and the distance must be the same for both sides of the tire. If the GG ring in not concentric with the rim flange, it is recommended that the “inflate-twice” procedure also be used in mounting tubeless tires in order to seat beads properly.

(9) Tube type tires should always be aired once before the valve core is installed. All tube type radial tires should be inflated twice. To inflate twice, the tire is inflated to full inflation pressure, then all the air is let out and the tire is re-inflated. The first inflation is done to seat the bead of the tire, but tends to over stretch the tube and flap. Completely deflating the tire allows the tube and flap to relax. The full deflation and re-inflation stretches the tube and flap uniformly. During the first inflation, the airing should be stopped at about 70 kPa (10 psi), and the side ring or lock ring should be checked carefully to make sure it is properly seated. Also, it is recommended that the side ring or lock ring seating be checked at 70 kPa (10 psi) during the second inflation.

WARNING

Never, under any circumstances, attempt to seat rim components by tapping with mallet when tire is inflated or partially inflated. *Deflate the tire first.*

Always use a safety cage or approved safety device and extension hose with air gauge and clip-on air chuck for airing a tire on a multi-piece rim or single piece rim.

c. After the tire is mounted and inflated, the tire/wheel assembly should be stored indoors (see paragraph 3.1.1) for 24 hours to check its air retention, if feasible. Just prior to being put in service, the pressure in the tire should be checked and compared with the initial value applied. If the pressure is more than 34 kPa (5 psi) lower, the tire/wheel assembly should be checked for a leak.

d. Installation of run flat devices can complicate the tire mounting and demounting process. Additional lubricant is typically required in the areas of runflat to tire contact. Since there are numerous runflat designs and devices available, refer to the runflat manufacturers recommended procedures for installing the runflat device into the tire cavity and the mounting of the tire and runflat assembly onto the wheel. When inspecting tires that have been used with runflat devices look for damage (typically chafing) in the liner caused by incidental contact from the runflat when the tire deflects from vertical and lateral loads. The liner goes from bead to bead providing a layer of rubber that resists air diffusion through the tire crown and sidewall.

e. Always deflate any tire to be removed prior to loosening rim or wheel nuts. Bead lubricant must be used when demounting tubeless tires.

3.2 Test Controls.

3.2.1 Tire Rotation.

The rotation of military tires to different positions on the vehicle during tire tests is not desirable, primarily because of different wear characteristics of the military cross country tread on steering axles versus non-steering axles. Moving damaged/degraded tires to different wheel stations will be analyzed during degraded mobility tests.

3.2.2 Test Vehicles.

When more than one vehicle is involved in a comparative test of tires, all vehicles should be operated simultaneously, if possible. Should one vehicle break down the test is stopped until all vehicles are operational. The road speed and mission profiles of the vehicles for the group are carefully controlled.

3.2.3 Use of Chains.

a. Tire chains can be helpful, providing additional traction in severe weather conditions. For radial tires, only use chains that are specifically designed for radial tires. These chains typically have shorter cross chains than older designs and allow the position of the side chains to be higher on the tire sidewall, thus allowing the sidewall to flex as designed.

b. Be sure to use the proper chain size for the tire on which it is being attached. Refer to the vehicle or tire manufacturer for recommended chain sizes. Hand tighten chains when they are first applied. After a short run-in period readjust to ensure a continued snug fit. Serious sidewall damage and vehicle damage can result from loose chains.

c. Check for adequate dual spacing, especially if using single tire chains on each tire of a dual tire assembly. The greater deflection of radial tires may require more dual spacing in certain applications. When using tire chains, a minimum of 5 centimeters (cm) (2 in.) additional clearance is required to avoid interference.

d. Refer to the vehicle specific Technical Manual (TM) for guidance on traction aids. The TM will provide information on which wheel positions should be considered, speed limitations, and the appropriate National Stock Number (NSN) for ordering wheel chains based on tire size. Chapter 21 of Field Manual (FM) 21-305, "Manual for the Wheeled Vehicle Driver"[10] provides general installation and operating guidelines for chain use.

e. Remove chains as soon as they are no longer needed.

3.2.4 Dual Tire Considerations.

a. Mismatched dual tires can have a detrimental effect on the life of tires. An underinflated tire on a dual assembly shifts its share of the load to the adjacent tire that then becomes overloaded and frequently fails prematurely. A similar action occurs when one tire's diameter is smaller than the other. Improperly matched duals are subject to accelerated wear. The overall result is abnormal wear for both tires at that particular wheel station. Improperly matched dual tires may also lead to sudden air loss as a result of one tire being required to deflect more in normal service.

b. The tire's overall diameter will govern the revolutions per mile obtained from a given tire. Particular attention should be given to match the tire revolutions per mile with drive axle units that are coupled directly together. The tires of tandem driving axles should be inspected and matched at regular periods, as determined by the type of service. Tire circumference of duals should be as close as possible with a maximum tire circumference tolerance of 19 mm (0.75 in.) for tire sizes up to 8.25R20 and 38 mm (1.50 in.) maximum circumference tolerance for tire sizes of 9.00R20 and larger. When significant differences in tire diameters are detected mount the smaller diameter tire on the inside. The outside tire typically wears faster than the inside tire.

c. Tires mounted too close together in a dual tire application do not permit adequate air circulation to dissipate tire heat. Heat increases tire tread loss rate and reduces the overall tire durability. When a truck is loaded, or if tire pressures are low, insufficient spacing can cause the sidewalls of the tires to rub together and overheat due to continuous friction. If the space between the tires is too great there will be excessive tire scuff of the outside tire each time a turn is made.

d. The proper dual spacing for radial tires is the same as for bias ply. The dual spacing is the sum of the rim offsets and the spacer width. To determine the proper tire clearance, subtract the section width from the figure for dual spacing. Use the loaded section width (LS) presented in the Tire and Rim Yearbook (reference 7) or the width of the tires can be measured under load. The rim offset determines dual spacing and affects vehicle clearance and the overall vehicle width. Any change in offset of the inside rim will change vehicle clearance proportionally. Any offset changes of the outside rims will change the overall distance across the vehicle from outside tire wall to outside tire wall.

3.2.5 Tire Inspection.

a. Tire inspections are conducted to various degrees depending on the test objectives. On-vehicle inspections are conducted at least once per shift by the test driver and may consist of “walk around” visual inspections. Prior to specific performance tests a physical check of inflation pressure should be conducted. Final tire inspections should be done off the vehicle if possible, and each tire should be demounted from the rim for examination.

b. The Federal Motor Carrier Safety Administration (FMCSA) Regulation Part 393.75: Tires[11], require at least 4/32 in. of tread depth on the front tires of any bus, truck, or truck tractor covered by that law, and the standard 2/32 in. remaining tread depth on the other wheel positions. Also covered in the regulation is that no motor vehicle shall be operated on any tire that:

(1) Has body ply or belt material exposed through the tread or sidewall,

(2) Has any tread or sidewall separation,

(3) Is flat or has an audible leak, or

(4) Has a cut to the extent that the ply or belt material is exposed.

c. Detailed tire wear should be characterized using ASTM F1426 “Standard Practice for Identifying Tire Tread Surface Irregular Wear Patterns Resulting from Tire Use”[12] as a general guide. This standard provides the instruction and nomenclature needed to analyze the wear features of tread patterns on a tire for conditions short of total wear out. Tire inspections should include physical, visual, and tactile examinations. Tire damage and/or failures should be examined and cataloged following the reference “Tire Forensic Investigation – Analyzing Tire Failure”[13] by Thomas Giapponi.

d. The basic definitions of general tread pattern features are described in ASTM F1426 and presented below. Figure 2 shows the tread pattern descriptors.

(1) A tread band is defined as the annular volume of rubber that encompasses the outer pavement-contacting periphery of a tire; the width is normally much greater than the thickness, and both of these dimensions vary with tire size.

(2) A void is defined as the volume (in the tread band) defined by the lack of rubber; the depth dimension of this volume may vary from point to point in (on) the tread band.

(3) A groove is defined as a void that is relatively narrow compared to its length.

(4) Projection is defined as the pavement contacting area of the tread band bounded by void.

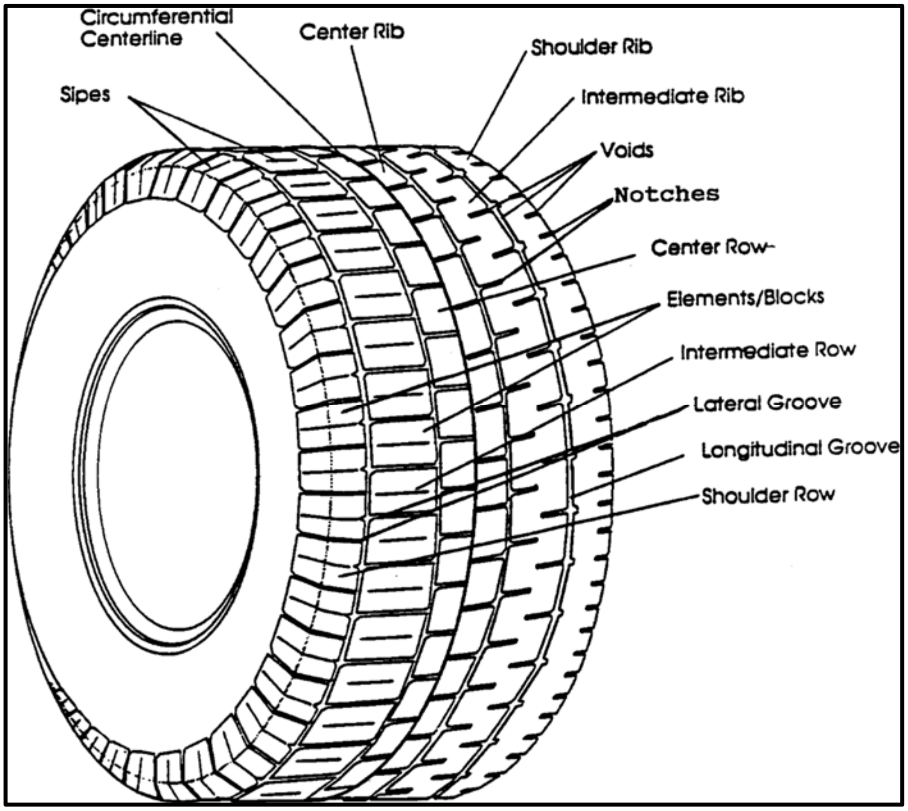

Figure 2. Tire tread pattern descriptors (ASTM F1426).

e. Sub-classifications of basic tread pattern features, also taken from ASTM F142.6 are defined as follows:

(1) Grooves are major features that are further characterized as follows:

(a) A longitudinal groove is defined as an endless groove that has its major dimension substantially parallel to the tire circumferential centerline. The walls of the groove may not be perfectly parallel planes, but may have short alternating sections of the wall at angles to the tire circumferential centerline.

(b) A lateral groove is defined as a groove that has its long dimension oriented at a direction nonparallel to the tire circumferential centerline. It typically opens into a void at both ends.

(2) Secondary groove-like features are defined as follows:

(a) A notch is defined as a groove smaller in both width and length than a lateral groove that contains one closed end.

(b) A sipe is a molded or cut rectangular void that is substantially narrower than the major grooves or voids.

f. Projections are major pavement contacting tread band regions, defined as follows (Figure 2 shows typical tire tread descriptors):

(1) A rib is a continuous circumferential projection.

(2) A shoulder rib is a rib at or near the outer edge or shoulder of the tread band.

(3) A center rib is a rib at or near the circumferential centerline of the tread band.

(4) An intermediate rib is one or more rib(s) located between the centerline and the shoulder ribs of the tread band.

(5) An element or tread block is an isolated (totally bounded by void) projection.

(6) A row is a rib or a continuous collection of elements that lie on a circumferential line parallel to the circumferential centerline of the tread band.

(7) A shoulder row is a row located at or near the shoulder of the tread band.

(8) A center row is a row located at or near the circumferential centerline.

(9) An intermediate row is a row located between the circumferential centerline and the shoulder ribs/rows of the tread band.

g. Tire wear and structural integrity definitions are presented in the following section. Standard wear definitions are taken from ASTM F1426 for uniform and irregular wear. When documenting tire conditions these definitions should be used. Uniform wear is defined by equal tread loss of the pavement contacting area resulting in a smooth appearance of all parts of the tread pattern. Irregular wear is characterized by substantial variations of tread loss across the contact patch.

h. Definitions of irregular wear are presented for three categories:

(1) Intra-projection wear features.

(2) Inter-projection wear features.

(3) Independent (of projection) wear features.

i. Intra-projection (irregular) wear features are irregular wear characterized by a different wear rate at two or more locations within a given projection. Included are:

(1) Heel-toe wear is characterized by different wear rates at the leading and trailing edges of a projection.

(2) Feathering is characterized by thin strips of rubber extending from the edge of the projection.

j. Inter-projection (irregular) wear features are irregular wear characterized by different wear rates on one or more adjacent projections (either transverse or circumferential orientation). Examples include:

(1) Shoulder wear characterized by an increased wear rate in the outer edge of the shoulder rib or row compared to the inner shoulder edge.

(2) Row/rib wear characterized by a greater wear rate in one or more rows/ribs; the increased wear rate may occur at one or more circumferential locations in/on a given row/rib and is independent of individual projections resulting in a step-off in tread depth between adjacent rows/ribs.

(3) Center wear characterized by a wear rate continuously increasing from shoulder to center of the tread band.

k. Definitions for independent irregular wear features are defined as follows:

(1) Diagonal wear is irregular wear characterized by an increased wear rate region or band oriented from shoulder to shoulder at an angle that is not perpendicular to the circumferential centerline of the tread band.

(2) Cupping is irregular wear characterized by a variation in wear rate that may be periodic around the tread band circumference in one or more rows.

(3) Chip and tear is irregular wear characterized by a rough tread surface that may contain cracks, abrasion pits, or surface ruptures.

l. Tire structural degradation is broken down into 3 major failure modes. They include separation, cracking and rupture. Society of Automotive Engineers (SAE) J2047[14] is used as the reference for these definitions.

m. Separation is defined as tire degradation caused by separation of components.

(1) Bead separation is the bonding between components in the bead area.

(2) Ply separation is the de-lamination of adjacent tire plies.

(3) Cord separation is the separation of cords from the adjacent rubber.

(4) Tread separation is the separation of tread from the body or tread from belt.

(5) Belt edge separation is the separation between the tread and belt edge, or belt and carcass, or between belt plies.

(6) Inner liner separation is the separation of the inner liner from the carcass.

(7) Sidewall separation is the separation of the outer rubber compound from the cord material in the sidewall.

(8) A splice opening is a separation of overlapping or butting ends of a component.

(9) A junction opening is a separation of tread, sidewall, or inner liner splices.

(10) Chunking is the tearing out of sizable pieces from the tread elements.

(11) Blistering is a bubble-like void in tire structure.

(12) Tearing is a massive removal of lugs or parts of the tread.

n. Cracking is tire degradation caused by cracks in tread, sidewall, and inner liner.

(1) Flex cracking are deep cracks primarily caused by flexure fatigue.

(2) Groove cracking are cracks in the tread grooves.

(3) Splice cracking are cracks or a crack pattern originating at a splice.

(4) Juncture cracking is a crack originating at a juncture of two components and propagating randomly.

(5) Weather cracking are surface cracks induced usually by the action of ozone on sidewall areas under tension.

(6) Checking is small, closely grouped network cracks of little depth, caused by the action of ozone.

o. Rupture is defined as tire damage caused by cutting and tearing of tire components (including cords) due to excessive flexing, impact or road hazards.

(1) An impact break is a rupture of the tire carcass caused by sudden shock.

(2) A blowout is a sudden bursting of a tire.

p. A puncture is a hole in the tire caused by a sharp object.

3.2.6 Runflat Inspection.

a. Wheel assemblies equipped with runflat devices should be inspected by disassembling a representative sample. The runflat devices are installed according to the manufacturer's recommendations and marked in a way to identify any slip relative to the rim. All fasteners are torqued to the manufacturer's recommendations and striped to indicate any change due to testing.

b. Measurements should include:

(1) Inner diameter, mm (in.).

(2) Outer diameter, mm (in.).

(3) Foot width, mm (in.).

(4) Bead width, mm (in.).

(5) Weight of each component, kg (lb).

(6) Total weight, as installed (runflat device), kg (lb).

3.2.7 Rim Inspection.

a. Each rim must be marked with the following information in lettering not less than 3 mm in height, and impressed or embossed to a depth or height of not less than 0.125 mm. The rim designation, rim size and DOT symbol must appear on the weather side of the rim[15].

(1) A designation that indicates the source of rims published nominal dimensions, as follows:

(a) T - The Tire and Rim Association.

(b) E - The European Tyre and Rim Technical Organization.

(c) N - Independent listed with NHTSA.

(2) Rim size designation (diameter x width).

(3) The symbol DOT.

(4) Rim load rating.

(5) Rim type.

(6) Rim material.

b. Inspect rims periodically for cracks. Replace any cracked, badly worn, damaged, or severely rusted components with new parts of correct size and type. Mark or tag the unusable parts as scrap and remove them from the service area. Do not, under any circumstances, attempt to rework, weld, heat, or braze any rim components that are cracked, broken, or damaged.

c. Diameter and rim width measurements will be made using the procedures in the current TRA Yearbook. Lateral and radial runouts are measured in the bead seat areas. Rims with only one fixed flange will be measured on the fixed side for lateral runout. Tolerances for lateral and radial runout are presented in Table 2. Prior to measurement, each wheel will be visually inspected for paint runs or other abnormalities that would cause measurement errors. The rims can be prepared by light filing or sanding.

TABLE 2. LATERAL AND RADIAL RUNOUT

LATERAL AND RADIAL RUNOUT TOLERANCE (FEDERAL MOTOR VEHICLE SAFETY STANDARD (FMVSS) 119[16])			
LATERAL		RADIAL	
WIDTH, in.	RUNOUT, in.	DIAMETER, in.	RUNOUT, in.
Up to 8	0.040	Up to 15	0.030
8.1 to 10	0.050	15.1 to 17.5	0.035
10.1 to 12	0.060	17.6 to 20.0	0.040
12.1 to 14	0.070	20.1 to 22.5	0.045
14.1 to 16	0.080	22.6 and greater	0.050
16.1 and greater	0.090		

3.2.8 Tire Break-in.

Tire break-in procedures vary considerably and should be followed depending on which specific performance test is being conducted and what procedure is called out. Some procedure specific break-in instructions are presented below.

a. SAE J2181 Steady-State Circular Test Procedure for Trucks and Buses[17] recommends that new tires have 90 to 120 miles of "normal" driving on them. Tires should have at least 50% of the original tread depth remaining.

b. SAE J1263 Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques[18] recommends that the test vehicle has accumulated a minimum of 300 miles and the tires have accumulated a minimum of 2175 miles with 50 of the original tread depth.

c. SAE J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques[19] recommends a minimum of 2175 miles accumulated on the vehicle and test tires with 4039 miles preferred.

d. SAE J2452 Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance[20] recommends a one hour warm-up at 50 mph followed by a 2 hour cool down period for each test condition. This procedure is designed for component level tire tests.

e. SAE J1526 JOINT TMC/SAE Fuel Consumption in-Service Test Procedure[21] is designed as a fleet comparison test. It recommends the vehicles be driven a minimum of 2000 miles and are given a one hour warm-up period prior to the fuel consumption test.

f. SAE J1491 Vehicle Acceleration Measurement[22] recommends that test tires are run a minimum of 100 miles and have 75% of the original tread depth remaining.

g. SAE J1269 Rolling Resistance Measurement Procedure for Passenger Car, Light Truck and Highway Truck and Bus Tires[23]. This break-in procedure consists of running the tire for two and a half hours at 50 mph, 100-percent rated tire load and 100 percent of the base inflation pressure (capped).

h. SAE J2014 Pneumatic Tire/Wheel/Runflat Assembly Qualifications for Military Tactical Wheeled Vehicles[24], Appendix A.2.3.5. An initial break-in period of 160 km (100 mile) shall be run at the maximum vehicle speed, not to exceed 90 km/hr (55 mph) on a dry, paved surface at the highway inflation pressure.

3.3 Restrictions.

If military personnel are required, ensure a Test Schedule and Review Committee (TSARC) request is submitted within one year from the start of testing or as early as possible. A Safety Release (SR) must be obtained from the U.S. Army Evaluation Center (AEC) prior to using military personnel as test participants.

4. TEST PROCEDURES.

4.1 Component-level Tests.

Several component-level tests are conducted on the ATC Roadway Simulator Tire Test Rig that allows use of two different tire constraint fixtures. The first tire restraint fixture, shown in Figure 3, is used for force and moment testing. The second restraint fixture, shown in Figure 4, is used for rolling resistance measurements. During force and moment testing, a wheel force transducer (e.g,. SWIFT Model 40 or 50) is used to measure the forces and moments produced by the tire, F_x, F_y, F_z, M_x, M_y, and M_z, as defined by SAE J670[25] and shown in Figure 5. For the rolling resistance measurements, a single force transducer is mounted below the spindle, measuring F_x with resolution of less than one pound.

Figure 3. Force and moment test fixture (RWS Tire Test Rig).

Figure 4. Rolling resistance test fixture.

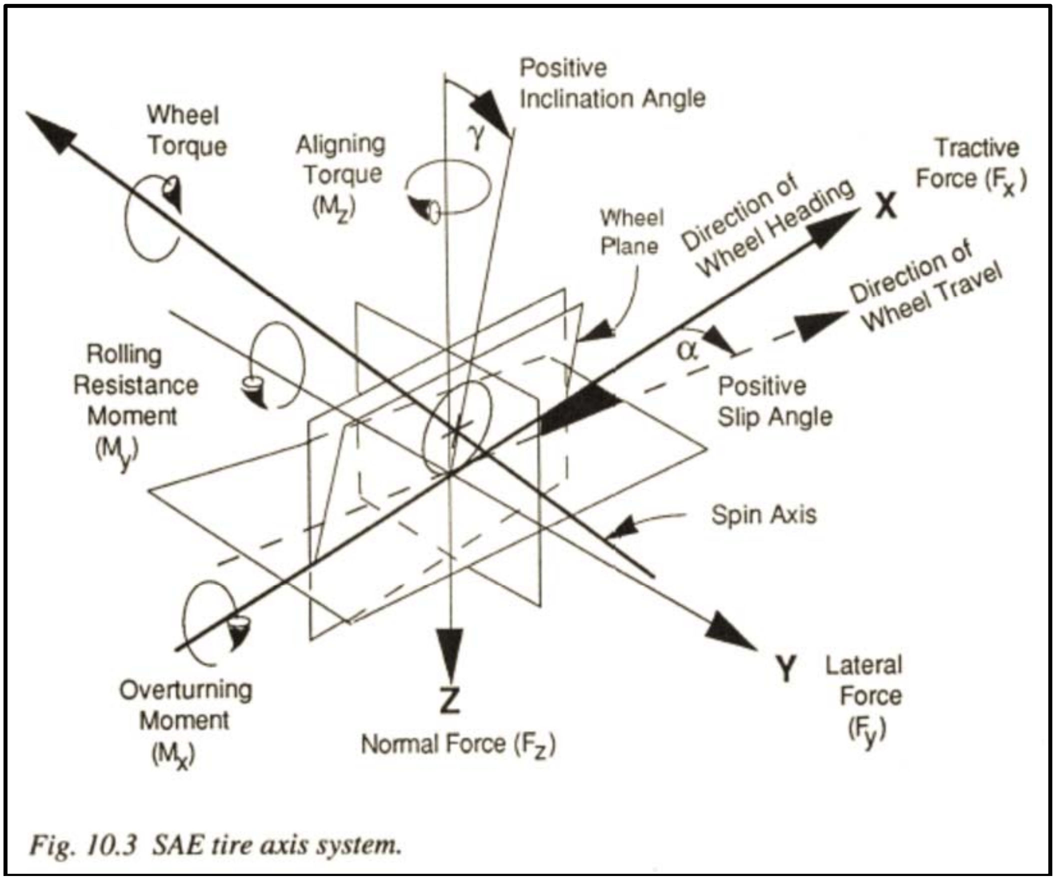

Figure 5. SAE tire axis coordinate system, per SAE J670.

4.1.1 Force and Moment.

a. Testing is performed in general accordance with SAE Recommended Practices J1106[26] and J1107[27]. The Flat-Trac stainless steel belt is lined with 120-grit 3M 348D Three-M-ite® resin bond cloth during testing, following industry practices. Tire load, pressure, and camber settings are specified by the customer. The inflation pressure of the unloaded tire should be adjusted to within ± 3.5 kPa (± 0.5 psi) of that specified for each test. If no tire pressure regulation is used, tire pressure may be inflated to 28 kPa (4 psi) above the cold inflation specification of interest to simulate the pressure increase that is encountered in road operation. This option is left to the discretion of the test engineer and customer. If a tire pressure regulator is used, the target tire pressure can be set prior to testing. Both the tire structure and the tread surface must be conditioned to achieve a stable level of performance during a reasonable series of tests. The tire should be exercised to remove local distortions, residual stresses, and manufacturing residue and to and ensure bead seating.

b. Data are often processed to produce a Pacejka tire model, which is a mathematical model predicting lateral tire force and aligning torque generation for various slip angles and vertical loads. The model produces a series of performance curves that best fit the test data, and

is a critical tool for vehicle dynamics modeling[28].

c. The general form of the Pacejka magic formula for lateral load is:

$$F_y = D * \sin\{C * \tan^{-1}[B * x - E(B * x - \tan^{-1}(B - x))]\} + S_v$$

d. The Pacejka magic formula for aligning torque is:

$$M_z = D * \sin\{C * \tan^{-1}[B * x - E(B * x - \tan^{-1}(B - x))]\} + S_v$$

where B, C, D, E and S_v represent curve fitting constants that describe the stiffness, shape, peak, curvature, and vertical shift, respectively of the measured parameters.

e. A typical test includes six or more vertical loads in uniform increments from approximately 40% through 160% of rated load. Data are recorded with the tire lifted from the road to obtain the null readings for each test setting. Slip angles of ± 15 degrees are used for characterization. The test tires are typically operated at 32 km/hr (20 mph) and are steered at a rate of 4 degrees per second. The camber angle is typically set not to exceed ± 3 degrees to minimize tire wear. Loss of inflation pressure may be encountered for a few tires at conditions of high slip angle and load. This is usually due to inadequate bead seating for the low speed laboratory conditions. Inflation should be checked at the end of a series of tests and tire operation monitored closely for the most severe part of the test series. Pressure loss in excess of 3.5 kPa (0.5 psi) should be corrected and the test rerun.

f. The tire performance attributes analyzed from the force and moment tests are the cornering stiffness, cornering coefficient, camber stiffness, aligning stiffness, and slip angle at peak aligning moment (an indicator of pneumatic trail behavior)[14]. The attributes are determined by measuring lateral force (F_y), vertical load (F_z), aligning moment (M_z), slip angle (α), and inclination (camber) angle (γ).

g. Tire force (F_x, F_y, and F_z) and moment (M_x, M_y, and M_z) measurements, as well as road speed, inclination angle, slip angle, tire pressure, tire temperature, and ambient temperature should be sampled and recorded at a minimum of 100 Hz with an appropriate anti-aliasing filter frequency. The sampling rate and filter cut-off frequency will be dependent on the dynamic range of the test profile.

h. The cornering stiffness and cornering coefficient are calculated using a linear fit of lateral force (F_y) versus slip angle over the lateral force range -0.4 F_z to 0.4 F_z. Camber stiffness is calculated using a linear fit of F_y over the inclination angle range -8 to 8 degrees. Aligning stiffness is calculated using a linear fit of aligning moment versus slip angle over the lateral force range -0.3 F_z to 0.3 F_z. The slip angles at the peak left and right steer aligning moments are averaged to calculate a single slip angle at the peak aligning moment.

4.1.2 Rolling Resistance.

a. Rolling resistance tests are conducted using SAE Recommended Practice J1269, as the guide. Detailed instructions for tire selection, preparation, measurements and analysis are provided. Rolling resistance testing requires a specific break-in procedure. The procedure consists of running the tire for 2.5 hours at 80 km/hr (50 mph), 100 percent rated tire load and 100% of the base inflation pressure (capped). The base inflation pressure is the inflation pressure corresponding to the maximum load listed in the tire load tables of the current TRA Yearbook or imprinted on the tire sidewall. After the break-in procedure is performed, the tires are required to cool over night before taking rolling resistance measurements.

b. The RWS tire test rig is designed to use the 'force' method outlined in SAE Recommended Practice J1269. The force method measures the reaction force at the tire spindle and converts that force to rolling resistance. Table 3 presents the standard test sequence for light truck tires. Table 4 presents the standard test sequence for highway truck and bus tires.

TABLE 3. ROLLING RESISTANCE TEST SEQUENCE FOR LIGHT TRUCK TIRES

TRIAL NO.	TIRE LOADING – PERCENT OF MAXIMUM RECOMMENDED TIRE LOAD	INFLATION PRESSURE – PERCENT OF RECOMMENDED INFLATION PRESSURE AT MAXIMUM LOAD
1	100	100 Capped[a]
2	70	60 Regulated[b]
3	70	110 Regulated
4	40	30 Regulated
5	40	60 Regulated
6	40	110 Regulated

TABLE 4. ROLLING RESISTANCE TEST SEQUENCE FOR HIGHWAY TRUCK AND BUS TIRES

TRIAL NO.	TIRE LOADING – PERCENT OF MAXIMUM RECOMMENDED TIRE LOAD	INFLATION PRESSURE – PERCENT OF RECOMMENDED INFLATION PRESSURE AT MAXIMUM LOAD
1	100	100 Capped
2	100	95 Regulated
3	75	70 Regulated
4	50	120 Regulated
5	25	70 Regulated

(1) Capped inflation pressure is controlled by inflating the tire to the required pressure prior to testing while the tire is at ambient temperature of the test area and then sealing the air in the tire during testing with a valve or cap.

(2) Regulated inflation pressure is achieved by inflating the tire to the required pressure independent of its temperature, and maintaining this inflation pressure during testing.

c. Additional test configurations may be needed to capture specific vehicle configuration attributes for characterization. Those include specific tire pressures coinciding with central tire inflation settings and tire deflection ratios as needed to support mobility and trafficability analysis. A typical range of tire deflection encountered for off-road performance is 15 to 45-percent.

4.1.3 Steer Frequency Response.

a. Steer frequency response tests are conducted using the force and moment test fixture. The Flat-Trac stainless steel belt is lined with 120-grit 3M 348D Three-M-ite® resin bond cloth during testing, following industry practices. Frequency response testing requires a break-in and warm-up procedure similar to that used for force and moment characterization tests.

b. Each test sequence consists of a series of sine steer events at discrete frequencies, listed in Table 5. The series is repeated for each of the road speeds, also listed in Table 5. The steer amplitude is ± 1 degree, and tire inclination angle is set to zero throughout testing. Tire pressure is typically set at the recommended highway tire pressure. Lateral force, steer angle, vertical load, and road speed are sampled and recorded at a minimum of 100 Hertz (Hz) (200 Hz is preferred). Post-test digital filtering is used to avoid adding phase lag to the measurements.

c. Bode plots of lateral force gain and phase lag versus steer frequency are produced for each test speed. Lateral force gain is normalized to the 0.1-Hz lateral force measurement. The primary attribute from the Bode plots is phase lag as a measure of the relaxation length of the tire. Relaxation length provides a distance-based measure of tire responsiveness and phase lag proves a time-based measure. The frequency response (Bode plot) approach provides response data over a broader spectrum of driving conditions than typical low-speed relaxation length measurements. Steering phase lag, as expressed in degrees, is calculated by dividing the time delay between the sinusoidal steer command and the sinusoidal lateral force response by the overall time period of the steer frequency. In general terms, less phase lag results in better tire responsiveness. Figure 6 shows presentation of the lateral force gain and phase lag versus frequency for a typical steering frequency response test.

TABLE 5. STEER FREQUENCY RESPONSE TEST PROCEDURE

STEERING		NOMINAL TIRE LOAD, PERCENT OF MAXIMUM LOAD	ROAD SPEED, km/hr (mph)
FREQUENCY, Hz	REPETITIONS		
0.1	3	80	10 (6.2) 20 (12.4) 40 (24.9) 60 (37.3) 100 (62.2)
0.2	3		
0.4	4		
0.6	4		
0.8	4		
1.0	4		
1.5	10		
2.0	10		
2.5	10		
3.0	10		
5.0	10		

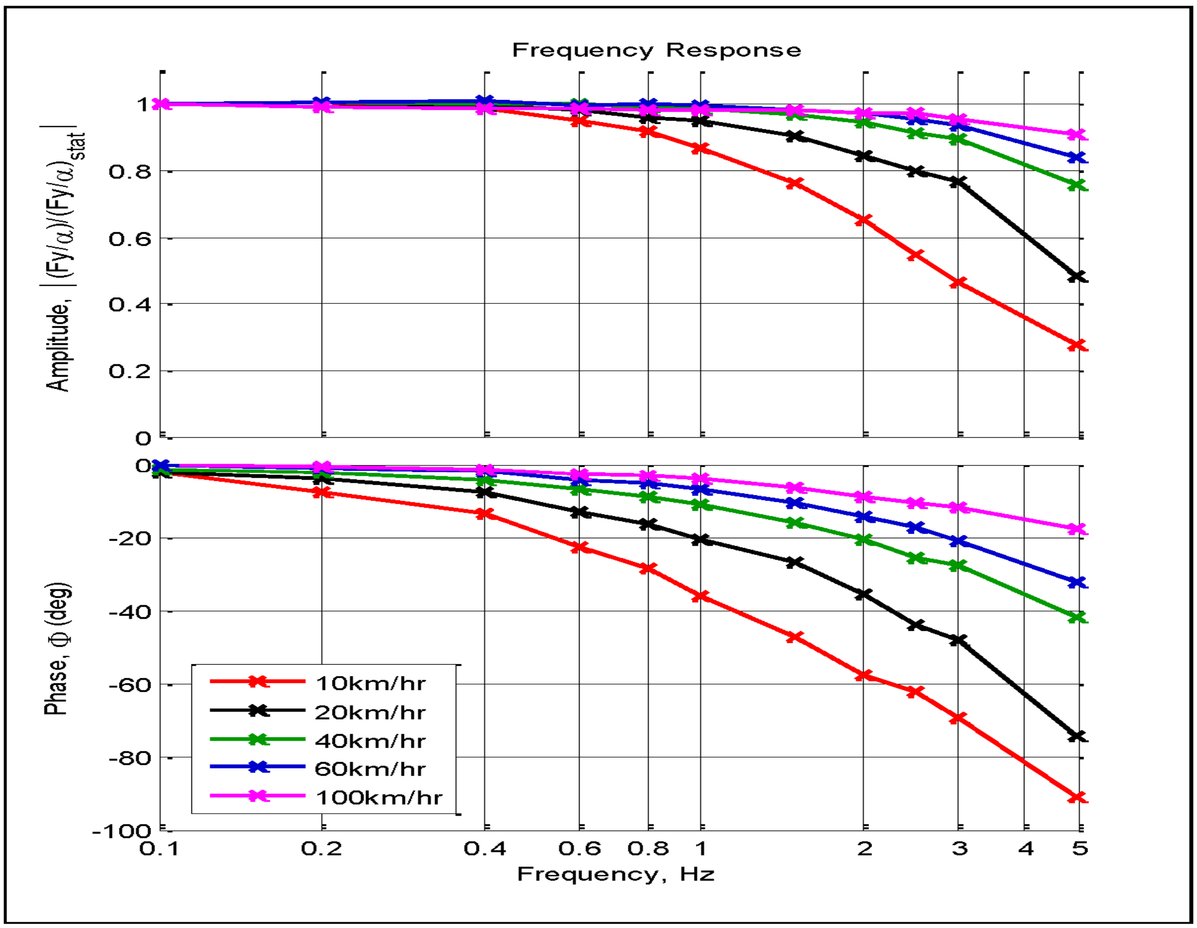

Figure 6. Sample bode plot, steer frequency response.

4.1.4 Load-Deflection.

a. Tire deflection as a function of vertical tire load is a critical tire attribute that is measured using the tire test rig. Under static conditions the tire is loaded in the vertical direction while the tire deflection is precisely measured. Tests are initiated in the unloaded condition. The sidewall deflection is determined by measuring the loaded section height of the tire and subtracting that value from the height of the unloaded section. Data are typically presented as percentage of unloaded deflections. Points of particular interest should cover the weight distribution range of the vehicle(s) that the tire type is installed. The deflection at the tire's rated capacity should be measured as well as the point at which the runflat contacts the tire liner, if equipped. The inflation pressure, vertical tire load, and nominal and specific tire pressures are inter-related. The development of a surface plot allows estimates of ground pressure to be made if inflation pressure and load are known. Figure 7 shows an example of tire data from the tire test rig.

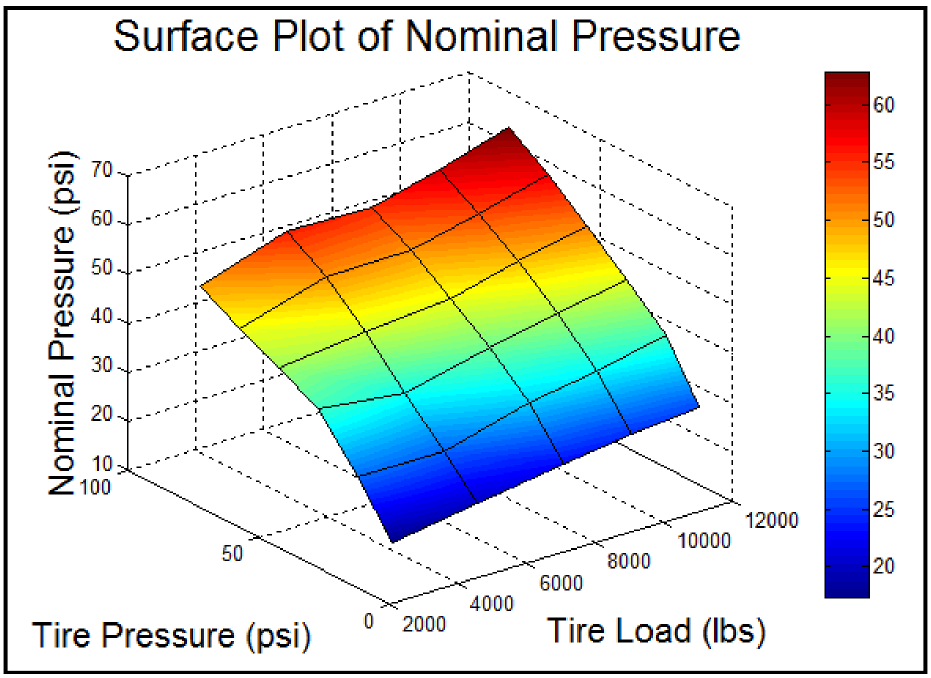

Figure 7. Typical surface plot data.

b. Tire contact area is measured concurrent with the load deflection tests using TOP 02-2-801[29] as a guide. The tire contact area is captured for each test condition using inked tire prints. Figure 8 shows a typical tire print. General descriptions of the contact areas should include the following:

(1) Nominal area, mm^2 (in^2).

(2) Specific area, mm^2 (in^2).

(3) Void area (nominal – specific area), cm^2 (in^2).

(4) Ground contact length at the contact patch, mm (in.).

(5) Contact patch width, mm (in.).

(6) General descriptor of contact patch shape.

(a) Circular.

(b) Elliptical.

(c) Square.

(d) Rectangular.

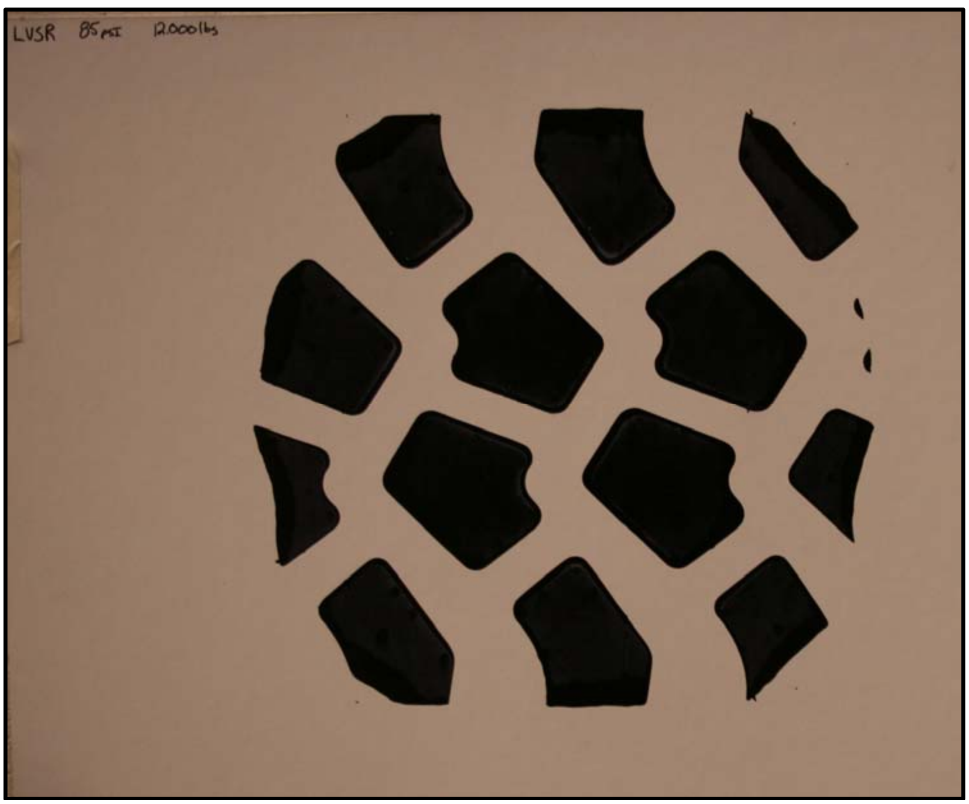

Figure 8. Typical ink print of tire contact area.

c. Additional tread descriptors (per DOT HS-810 561[30]) are shown in Figure 9.

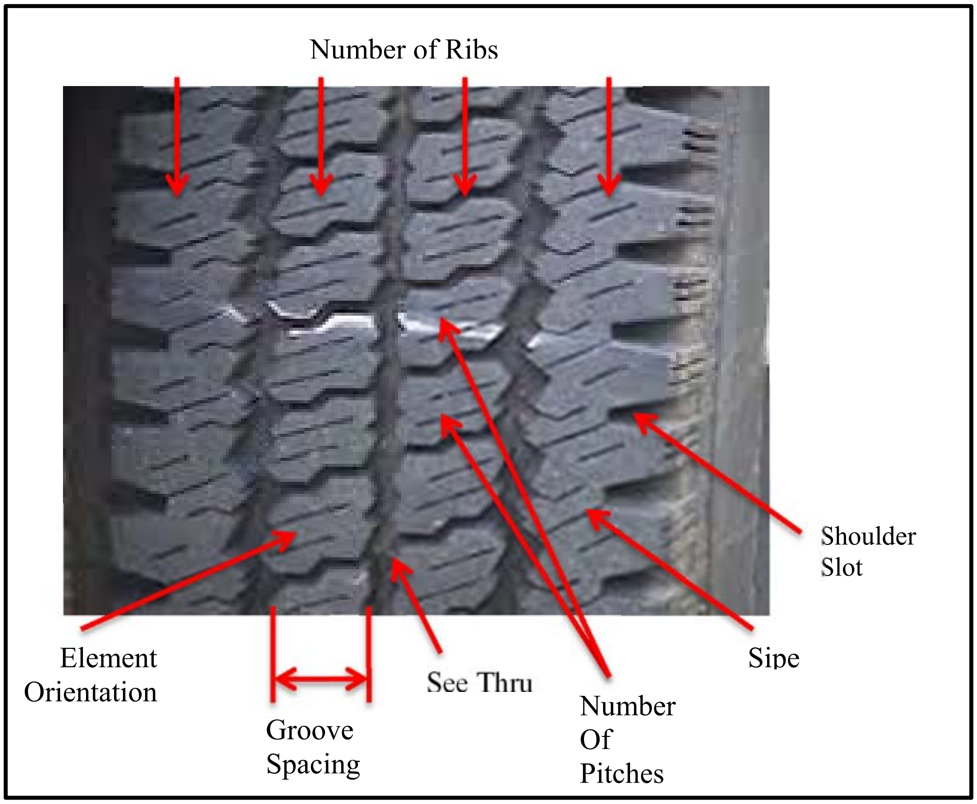

Figure 9. Tire tread descriptors.

4.1.5 <u>Tire Physical Characteristics</u>.

a. Pertinent physical characteristics are required for characterization and description of the tire/wheel assembly. SAE Vehicle Information Report J2047, "Tire Performance Technology" assembles existing tire terms and their definitions developed by different standards organizations into a single reference of technical terms related to tire performance.

b. The primary measurements/definitions are presented below:

(1) Tire carcass section height, unloaded (h): Distance from the lip of the rim flange to the periphery of the tire, exclusive of tread, measured along the vertical center line of the cross section of the inflated but unloaded tire.

(2) Tire section width (b): Maximum outside width of the cross section of the inflated but unloaded tire.

(3) Tire (outside) diameter (d): Outside diameter, including tread, of the inflated but unloaded tire.

(4) Tire aspect ratio (h/b): Describes the general shape of a tire's cross- section. Tires of h/b near one are "high molded;" tires with h/b below about 0.75 are "low profile.

(5) Tire shape factor (b/d): Most tires for routine off-road service today have b/d values in the 0.20 to 0.35 range. A growing family of tires for use in areas of very low soil strength (swamplands, marshes, tundra, etc.) have larger b/d values~0.40 to 1 and higher.

(6) Nominal rim diameter (d_r): d_r is defined as "diameter at the shoulder of the rim.

(7) Rim width (b_r): b_r as the width of the rim from shoulder to shoulder.

(8) The individual tire weight should be measured. A description of tire, rim, runflat, and wheel assembly should be noted.

c. The following paragraphs further define and describe the measurement process for each tire dimension. The determination of the un-deflected radius is measured by anchoring the end of the calibrated steel tape at the crown of the mounted and inflated tire or at a nearby maximum radius location and carefully stretched circumferentially around the tire parallel to the tire-wheel plane. The circumference is recorded and then divided by 2π to give the un-deflected radius. If a Pi - tape is used the diameter is read directly.

d. The loaded tire radius is determined by marking the tire location on a smooth, level, paved surface and then driving the vehicle without steering at walking speed, while counting 10 revolutions of the tire. The distance travelled is measured and converted to a rolling distance in m/rev (ft/rev). The loaded tire radius is calculated by dividing by 2π. The loaded tire radius should be measured and reported to ± 1 mm (± 0.04 in.) for light truck tires and ± 2.5 mm (± 0.10 in.) for highway truck and bus tires.

e. The section height is one-half of the wheel's nominal diameter subtracted from the tire's un-deflected radius. As noted in SAE J2047, the nominal rim diameter is the figure in the rim specification that designates or approximates the rim diameter. For example, in the case of an 18 X 10J - ISO wheel, 18 is the nominal diameter expressed in inches.

f. The determination of the section width is measured at each of the three marked locations determined in paragraph 3.1.2 using calipers. Overall width includes protective ribs, bars, and decorations that are common on tire sidewalls. The height of the protective ribs, bars, and decorations included in the overall width measurement at a marked location is determined using the depth gage. The reported value of section width is the average of the results for each of the three individual marked locations.

4.1.6 <u>Tire Endurance (FMVSS 119)</u>.

a. The purpose of the endurance test is to analyze heavy truck tire performance at highway speeds for sustained operation. The endurance test (FMVSS 119) applies to truck tires with load ranges F through N that are not for speed-restricted service. The test parameters used for the endurance test include ground speed, load, inflation pressure, duration, and ambient

temperature.

b. The test speed for the endurance test depends on the load range of the tire. Load range F tires are tested at 64 km/hr (40 mph), load range G tires are tested at 56 km/hr (35 mph), and tires with a load range H, J, L, M, or N are tested at 48 km/hr (30 mph).

c. Tire loading and durations for the endurance test are identical for all load ranges F through N and are specified as a percentage of the maximum load rating of the tire. The percentages are 66 percent, 84 percent, and 101 percent. The loads are applied in a stepped fashion for durations of 7 hours, 16 hours, and 24 hours, respectively.

d. The test inflation pressure is the pressure corresponding to the maximum load rating labeled on the tire's sidewall for vehicle applications that employ CTIS. For vehicle applications without CTIS the inflation pressure should be set at 80 percent of the sidewall-labeled inflation pressure that corresponds to the tire's maximum load rating. According to the results of a FMCSA's tire pressure monitoring survey of 6,087 heavy trucks with over 35,000 tires sampled, approximately 20 percent of the vehicles had at least one tire that was under-inflated by 20 psi or more (per FMCSA study, “Commercial Vehicle Tire Condition Sensors”[31]). As a result, testing with some level of under-inflation reflects the reality of what heavy truck tires typically experience in service.

e. The ambient temperature specified for the endurance test is 35 °C ± 3 °C (95 °F ± 5 °F).

f. Tire loading, vehicle speed, and inflation pressure scenarios falling outside the tire sidewall data should be tested. Tire loading percentages should be calculated using the measured overloaded tire load. The highest sustained vehicle speed expected should be used in lieu of the load range based speed presented above. Tire pressures, if significantly higher or lower than the maximum tire pressure should be used.

g. In the absence of specific guidance for tire temperature limits, the following general guidance should be followed. Ambient temperature, load, speed, inflation pressure, wheel position, and tread pattern all impact the tread temperature of a truck tire. In normal operating conditions the surface tread temperatures should stabilize in the range of 65 to 93 °C (150 to 200 °F).

h. As a tire is heated, the molecular activity within the compound increases. At temperatures approaching 121 °C (250 °F) the tire starts to lose strength and the influence of other internal stresses becomes greater. During the manufacturing process, tire vulcanization occurs at 121 to 160 °C (250 to 320 °F). Tire reversion also begins around 121 °C (250 °F). The molecular bonds break down and the tire starts to physically come apart (reversion). If external heat continues to be applied to the tire to maintain temperatures over 300 °C, the tire can catch fire. Once a tire begins to burn, it will generate enough heat to continue the combustion process. Time and rate of heat generation are factors that help determine if a tire destructs or burns. The best way to extinguish a fire that involves a tire is with a steady fog stream of water. The most

important factor is to eliminate the external heat source. Portable extinguishers are of little use in a tire fire since they do not have the capacity to remove the heat source and allow re-ignition.

4.2 Vehicle-level Tests.

4.2.1 Endurance.

a. An endurance test involves extended operations of one or more test items operating a series of cycles designed to simulate extended field use under controlled, repeatable proving ground conditions. The endurance test is the principal means of producing data for reliability and maintainability analysis.

b. A durability test is designed to demonstrate a specified probability and confidence that a vehicle, or a major component, will be able to operate under defined conditions for a specified distance or operating time before needing a major overhaul, replacement or salvage.

c. It is recommended that all vehicles have their tire pressures set in accordance with the vehicle manufacturers recommended setting for specific terrains. If equipped with a CTIS, those settings should be used for specific terrains. If no guidance is provided, vehicles generally operate on primary and secondary roads using a "highway" tire pressure setting. Vehicles operating on trails or cross-country terrains will generally use a "cross-country" tire pressure setting. Refer to paragraph 5.1.1 of TOP 02-2-506A[32] or Appendix A for terrain definitions.

d. Tire clearances should be verified during the initial inspection process. The vertical clearance should be determined, taking into account the motion ratio of the suspension, bump stop location, and wheel/suspension travel. Based on the suspension design some longitudinal motion can be expected depending on spring shackle location and bushing compliance. This clearance varies as the axles operate. The clearance of the tires on steering axles must be checked by turning the wheels from full left lock to full right lock, since the minimum clearance might occur at some intermediate point. Use of the vertical steps or a ramp travel index (RTI) fixture (Figure 10) is recommended to articulate the suspension while checking tire clearance.

Figure 10. Vertical step and RTI fixture checking tire clearance.

e. Each tire should be inspected and measured following the break-in. Measurements are made at a minimum of six equally-spaced locations around the periphery of the tire for the following: tread depth at crown and shoulders, section width, tread radius, tread arc width, outside diameter, and tread profile (SAE J2014).

f. Test courses and the percent mileage on each surface selected for the treadwear test shall reflect the mission profile of the vehicle. All tires shall be measured at the start of the test and at ideally eight to ten equally spaced mileage intervals corresponding with vehicle maintenance schedules. At each measurement interval the tires should be inspected for damage and irregular wear. Each tire tread condition will be photographed at the start of the test, mid-point, and test completion. Each tire's mileage, maximum, minimum, and average vehicle speed will be recorded at each measurement interval.

g. The tread depth will be measured and recorded when the tire is new, after 24-hour growth at rated inflation then adjusted to test tire pressure, and at approximately 1600-km (1000-mile) intervals. Tread depth measurement must not be taken at treadwear indicators (measurement device must bridge both sides of the groove for accurate measurement). Measure the tread depth for each groove at each measurement point. Determine the amount of tread depth reduction for each measurement at a given mileage interval by subtracting the latest measurement from the tread depth at zero km (mile) and record in 0.025 mm (0.001 in.) resolution. Calculate and record the tread depth reduction at each mileage measurement interval.

h. The wear rate in km/mm (mile/mil) will be determined by dividing the miles traveled for that interval by the mils of rubber worn away. This procedure will be followed for each measurement point on each groove at each of the six equally spaced measurement locations. The tire's average wear rate will be calculated by adding the wear rates of all measurement points and dividing by the total number of measurements for that individual tire. The overall average wear rate for all tires of a given design in the test will be determined by summing the wear rates for all tires and dividing by the total number of tires. The overall average wear rate will be plotted and compared for both the candidate and control tire at each mileage measurement interval. This graph will be used to establish a wear comparison between the candidate and control tire and as a signal for test or measurement of abnormalities that can occur at a given measurement mileage point.

i. General degrees of irregular wear are categorized as severe, moderate, slight, or none, and refer to the tire's state at the time of removal. Also, the mileage at first detection should be recorded. It is possible that a tire could experience some degree of irregular wear but the wear did not preclude the tire wearing to a tread depth at which it would normally be removed (SAE Paper 922485[33]).

j. Specific steering and suspension design features and/or vehicle alignment conditions can contribute to tire wear as a function of wheel position. If irregular wear is occurring additional measurements to include percent Ackerman correction (SAE Paper 912693[34]), wheelbase, tread, camber, toe, and drive axle(s) alignment data should be collected to use in the tire wear analysis.

k. Detailed tire wear should be characterized using ASTM F1426 as a general guide. This standard provides the instruction and nomenclature needed to analyze the wear features of tread patterns on a tire for conditions short of total wear out. Tire inspections should include physical, visual, and tactile examinations. Tire damage and/or failures should be examined and cataloged following the reference “Tire Forensic Investigation – Analyzing Tire Failure” by Thomas Giapponi (reference 13). Refer to paragraphs 3.2.5 through 3.2.7 of this document for definitions and inspection procedures for tires, runflat devices and rims.

4.2.2 Runflat.

a. The procedures in TOP 02-2-698[35] are commonly used to analyze runflat performance for tactical wheeled vehicles. Additional guidance is provided in The Finabel Agreement No A.20.A Combat Tyres[36].

b. A vehicle with one or two damaged tires must be capable of running for a total distance of 100 km (62 mi), [desirable 150 km (93 mi)], without the tires coming off the rims or starting to burn, and without its properties of steering, maneuverability, stability, braking, and speed being seriously affected under the following conditions:

(1) 3 km (1.9 mi) at maximum speed.

(2) 22 km (13.6 mi) at 50 km/hr (31 mph).

(3) 75 km (46.5 mi) at 25 km/hr (15.5 mph).

(4) + 50 km (31 mi) at 25 km/hr (15.5 mph) (desirable).

c. If the vehicle considered has more than 4 wheels, it is desirable that its performance levels should be maintained following the puncturing of all the tires on the same side of the vehicle.

d. Testing is typically stopped upon the occurrence of any of the following:

(1) Inability of the test driver to maintain control of the vehicle.

(2) Inability of the vehicle to be operated safely.

(3) Inability of the vehicle to maintain continuous mobility.

(4) Reduction in speed not attributed to measurement interval.

(5) Any of the wheel rims contacting the ground.

(6) Imminent, irreparable vehicle damage.

(7) Completion of required mileage accumulation.

e. The post-test inspection should include a tear down of the wheel assemblies. Any remaining deflated tire, wheel, and runflat parts are recovered and inspected for slip, wear, and damage. The inspection should also include an examination of the rims for bent or damaged flanges, tire to wheel slip, and tire beads and/or runflat spacers dislodged from the wheel.

4.2.3 Bead-slip.

Bead slip tests are conducted to determine the ability of tires to remain on their rims at reduced tire pressures under maximum wheel torque conditions. Straight-line runs are conducted in off-road conditions (sand or sandy loam) and repeated on paved surfaces with the tire pressure decreased in increments until bead slip occurs or the bead becomes unseated. Wheel loads are sustained and measured by applying drawbar loads with a mobile field dynamometer. Paved longitudinal grades can be used in the absence of a dynamometer. Bead slip will be measured by marking the tire/wheel combination as specified in paragraph 3.1.2.

4.2.4 Military Tire Bead Unseating.

a. Refer to paragraph A.4 of SAE Recommended Practice J2014 for the detailed data requirements, test course conditions and dimensions, test procedure, and instrumentation. The purpose of this test is to determine tire/rim slip, air loss, or bead unseating when operated at the minimum recommended inflation pressure. The test course is a “figure-8” and requires the test vehicle wheelbase and full-lock turning diameter measured at the centerline of the front axle travel path to calculate the test course radius of curvature (R) and the interconnecting straight sections (A). Figure 11 shows the course layout. The test area for the bead unseating test is sand (preferred) or sandy-loam (SP or SM-as determined by USCS). The depth of the material is at least 750 mm (30 in.), tilled to at least 200 mm (8 in.), and dried to a moisture content of less than 2.0% in the top 75 mm (3 in.). The cone index at the 75 mm (3 in.) depth should not exceed 100.

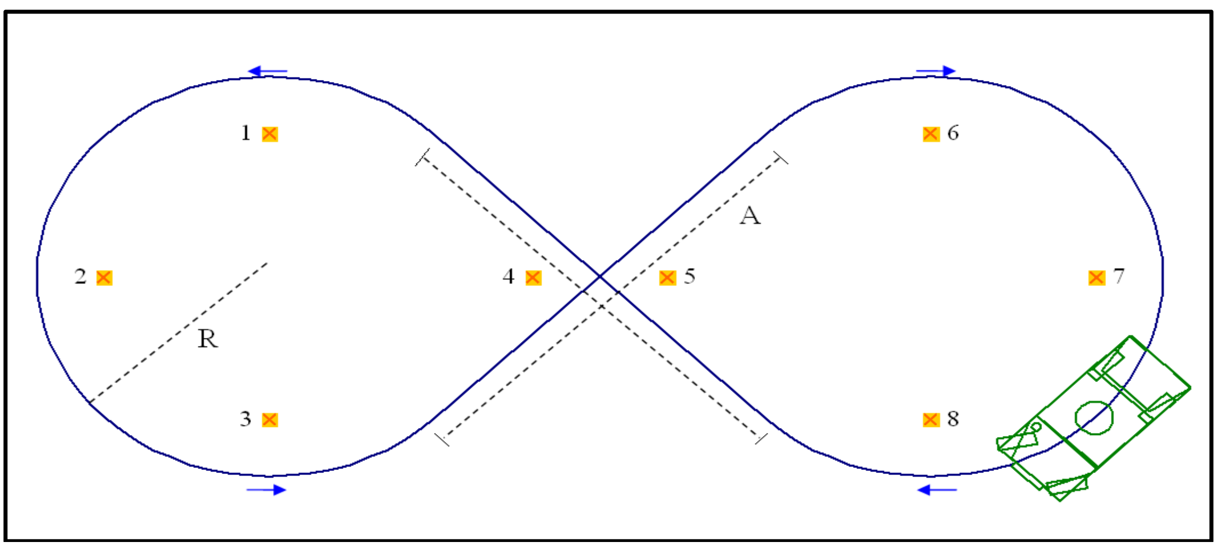

Figure 11. Test course dimension for bead unseating test.

b. The test vehicle is loaded so that each individual static test tire load is within ± 5% of the maximum tire load for the intended vehicle (unless otherwise specified). The cone penetrometer will be used to measure soil strength of the test area berm before and after each test sequence.

4.2.5 Central Tire Inflation System (CTIS).

Central tire inflation systems are military unique applications that allow the driver to adjust the tire pressure from the safety of the truck, optimizing the tire performance for specific operating terrain and conditions. The tires can be inflated and deflated using the on-board air system. Analysis of CTIS tests are based on the following:

a. Measurements are taken to determine the actual tire pressure at each wheel station for each driver selectable setting. The pressures are verified using an external handheld pressure gauge. At least three cycles throughout the pressure range of the CTIS should be conducted. It is important to capture tire characterization data at the measured CTIS pressure settings, where appropriate.

b. Adjustment of tire pressures should be independent of other vehicle subsystems. Tire pressure checks are conducted with the vehicle stationary on a paved, level surface at the recommended engine speed in accordance with the CTIS operational instructions set forth in the vehicle's TM. The time needed to inflate/deflate from one CTIS setting to the next is recorded. Inflation/deflation time begins when the target setting is selected and ended when the CTIS system indicates the target setting is achieved. The capability of the CTIS to warn the driver of excessive speed-at-pressure conditions is addressed by operating the vehicle 8 km/hr (5 mph) above the maximum speed for a given CTIS setting and measuring both the time until the over-speed alarm activates and the time required for the tires to inflate to the next higher CTIS setting. The maximum operating speed for each CTIS setting is determined from the CTIS operational instructions in the vehicle's operator's manual. Tire pressures are monitored using a wireless tire pressure monitoring system (TPMS) and through the vehicle Controller Area Network (CAN) bus system, if equipped. Typical databus parameters include vehicle speed, CTIS status, and primary and secondary air tank pressures. Video footage of the vehicle's drivers instrument panel is recorded to help document visual warnings displayed to the driver and should be synchronized with the engineering performance data in the on-board data acquisition system.

c. CTIS faults (single point failures) should be induced to analyze the capability of the system to automatically isolate any or all tires from the CTIS in the event of CTIS or tire failure and the capability of the system to assure safe operation of the vehicle. Faults consisting of simulating a tire leak by removing a tire plug in the CTIS module and/or a pneumatic line failure at a wheel assembly by removing the CTIS supply airline between the chassis and the wheel spindle are good choices. Any single leakage type failure can be introduced in the CTIS. Each vehicle should be inspected to identify potential failure modes other than those described above. Figure 12 shows a typical method for simulating a CTIS failure.

Figure 12. Typical method for simulating a CTIS failure.

d. For each simulated failure, the vehicle is set to highway mode and operated on a dry, paved, level surface at speeds between 24 and 40 km/hr (15 and 25 mph). Throughout testing, tire pressures are recorded and monitored wirelessly with a TPMS and also through the vehicle CAN bus system.

4.2.6 Tire Traction.

a. Traction tests should be conducted using SAE J2014, TOP 02-2-604[37], and TOP 02-2-619[38] as guides. Off-road test sites should be selected from TOP 01-1-011[39]. This test quantifies the driving traction performance of the tire(s) compared to a control tire tested under similar conditions. The selected test sites should be prepared to a uniform, level, relatively smooth condition with no vegetation. Course minimum dimensions are 6 m (20 ft) wide by 90 m (300 ft) long for drawbar tests. Prior to testing, each course is tilled to a uniform depth and soil strength. Cone penetrometer measurements are taken in a crosshatch pattern not exceeding 3 m (10 ft) to determine uniformity of soil strength. Soil samples are collected at three locations in each test lane at the surface and 150 mm (6 in.) depth. The moisture content of the soil is determined from these samples.

b. The driving traction performance of the control tire is used as a basis to compare the performance of the candidate tires. Tests will be conducted on one or more of the surface conditions for both the control and candidate tire tests. Desired surface conditions shall be selected in advance of the testing (e.g., SP and ML soil types).

c. Test results will be used to determine the tractive coefficient of both the control tire and candidate tire. The tractive coefficient from the tests shall be comparatively analyzed. Drawbar pull tests are used to develop the tractive coefficient and the drawbar pull-slip characteristics. Wheel slip will be computed using the individual wheel speed(s), loaded tire radius, and the true ground speed. Tests are repeated on a paved, level surface and similar data are collected.

d. The test vehicle will be equipped with the control or candidate tires in all wheel positions. The test vehicle will be run together with a mobile field dynamometer vehicle of adequate size and load to permit controlling the test vehicle speed. The connection between the vehicles will be a cable or a towbar parallel to the ground with a load cell capable of measuring the drawbar force. Instrumentation recording the drawbar force, time, wheel speeds, and true ground speed will be installed in the dynamometer vehicle. Sampling rate for the measurements will be a minimum of 100 samples per second. To build the drawbar pull-slip curve the test vehicle progresses in steps from a zero or no-load slip condition to a high-load/maximum-slip condition. Immediately following completion of the first test, the vehicle is repositioned at the beginning of the test lane offsetting the path of the prior test. A minimum of three drawbar tests will be conducted for each course condition and tire configuration.

4.2.7 Comparative Stopping Distance.

a. Comparative braking tests are conducted in accordance with SAE J2014. This vehicle test is used to compare the stopping distance of the control and candidate tire. The same test site and course conditions will be used for testing both the control and the candidate tires. The same test vehicle will also be used for each tire set. The test vehicle is equipped with a full set of the same tires for each brake test. The tires should have between 160 and 480 km (100 and 300 miles) of normal (break-in) operation on them prior to conducting the brake test. Testing is conducted on a straight, paved roadway, free of loose material with a slope that is less than 1%. The paved surface temperature should be less than 60 °C (140 °F) during testing. The vehicle speeds for the brake test will be as required by the vehicle's end item specification. Unless otherwise specified, test speeds will be 32 km/hr (20 mph) for dry pavement and 64 km/hr (40 mph) for dry and wet pavement.

b. The following procedure will be used to conduct the individual brake stops. Accelerate the vehicle to above the required test speed. With the automatic or manual transmission in gear and engaged, allow vehicle to coast and slow down to the required speed as indicated by the speed measuring device. At the required speed apply brakes at full effort. A predetermined brake pedal force may be used for consistent full-effort braking and to avoid wheel lockup. Record any unusual handling characteristics that occur during braking. Repeat the test traveling in the opposite direction. Repeat the test for a minimum of three runs in each direction. Allow sufficient time between each run to prevent the brakes and tires from overheating. Generally, operating the vehicle for one mile at the test speed is a sufficient time interval. When in doubt, install additional instrumentation to measure lining material temperature. Testing of the candidate and the control tires will be conducted in equivalent meteorological conditions using the same test vehicle, instrumentation, and test site. Comparative stopping distance and deceleration will be used to analyze the vehicle performance.

The stopping distance is defined as the distance traveled between the point at which the driver starts to move the braking control and the point at which the vehicle comes to rest. Since stopping distance on a given road surface varies approximately as the square of initial speed, comparative checks will require that the vehicle speed at which the brake control is initially moved be within 1% of the nominal value for each test condition. Refer to TOP 02-2-608[40] for detailed instrumentation, data presentation, and analysis techniques for wheeled vehicle brake tests.

4.2.8 Noise Level.

a. SAE J2047 defines tire noise and vibrations as presented below. Total tire noise is the aggregate of noise measured during the tire noise test. It is determined as the sum of individual noise elements.

b. Tread noise is airborne sound except squeal and slap, produced by interaction between the tire tread elements and a smooth road surface. Tonality is defined as tire noise (up to 2500 Hz) associated with the fundamental frequency and harmonics defined by the rate at which individual tread elements come into contact with the road surface. Sizzle is a tread noise characterized by a soft "frying" sound, particularly noticeable on a very smooth road surface.

c. Tread vibrations are vibrations (15-100 Hz) perceived tactually or audibly or both. Roughness is defined as vibrations (15-100 Hz) perceived tactually or audibly (or both), generated by a tire rolling on a smooth road surface and producing the sensation of driving on a coarse or irregular road surface. Harshness is a quickly decaying response to single sharp edge tire impact tactilely accompanied by noise in the 30-100 Hz range.

d. Squeal is defined as narrow-band airborne tire noise (600-1200 Hz) excited by either longitudinal slip or slip angle or both. Thump is a periodic vibration or audible sound (or both), generated by the tire and producing a pounding sensation synchronous with wheel rotation. Slap is a "smacking" noise produced by a tire traversing road seams such as tar strips and expansion joints at medium and high speeds. Moan is a low frequency (60-150 Hz) sound generated by higher harmonics of force and moment variations, runout, or tread element vibrations. Beat is a rhythmic sound generated by two dominant tones separated by 1 or 2 Hz. Growl is a low-frequency (300 Hz and lower) tread noise related to tire spin velocity (like tire noise generated by the metal grate surface of a bridge). Growl is most noticeable during deceleration, especially during braking.

e. Tire noise measurements are either near-field or far-field. Near-field measurements are conducted very close to the noise source (on the test vehicle or test trailer) using on-board sound intensity (OBSI) probes or sound pressure microphones. Far-field measurement tests consist of a vehicle with the test tires driving by a fixed microphone or set of microphones on the ground at a set distance from the test lane. Additional guidance on performing tire noise measurements are given by the Transportation Research Board of the National Archives Report 630[41] and International Standards Organization (ISO) 10844[42].

4.2.9 Ride, Handling, and Stability.

a. Refer to paragraph A.6 of SAE J2014 for detailed instruction. The test determines a tire's acceptability based on vehicle ride, handling and stability when subjectively rated by three qualified drivers operating the vehicle for 40 km (25 miles) each over a course which simulates the mission profile requirements of the vehicle, using the rating system described in SAE J1441[43]. The subjective rating scale shown in Figure 13 provides a means by which an analyst can assign numerical values to their subjective judgments about vehicle handling performance. The scale is unipolar and continuous with ten scalar points. Every second point is associated with an adjective to aid in the rating process. These adjectives have been selected to provide the best combination of linearity and common acceptance. The highest rating, a "10", corresponds to ideal vehicle performance, free of any possible deficiencies and is included as a high-level anchor point. The lowest rating, a "1", corresponds to totally deficient performance, and is also included for use as an anchor point. Handling performance of a vehicle with a rating between 5 and 10 is considered desirable, and performance of a vehicle with a rating between 1 and 5 is undesirable. A rating of 5 corresponds to borderline performance.

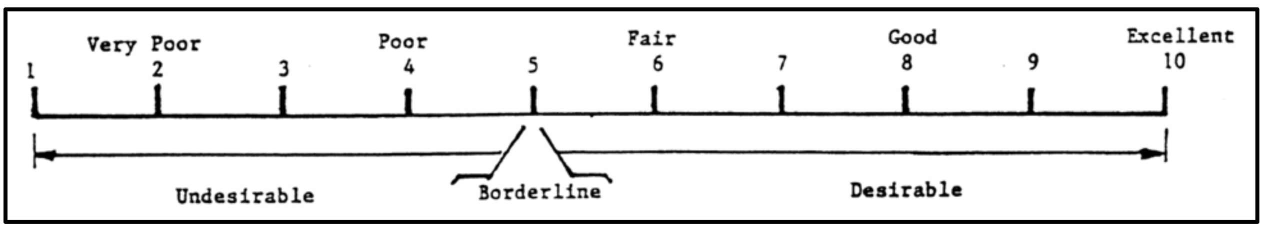

Figure 13. Subjective rating scale, SAE J1441.

b. Each driver subjects the vehicle to hard braking, sharp left and right turns, left and right cornering, and abrupt lane changes. Each of these maneuvers are repeated a minimum number of ten times for each phase of the mission profile. All testing is conducted on dry surfaces only at an ambient temperature of 4 to 38 °C (40 to 100 °F). All maneuvers are conducted at speeds that will not exceed the safe maneuvering speed of the vehicle. The roll over threshold of the test vehicle is measured with the control and candidate tires installed and inflated to the recommended pressure prior to the subjective handling tests. At the conclusion of testing, each driver rates performance of candidate tires (as compared to control tires) on a scale of 1 to 10, with the control tire value being arbitrarily set at 5. Vehicle drivers shall drive the test vehicle equipped with both the control tires, as well as the candidate tires, prior to making their judgment.

c. Quantitative analysis of vehicle handling should be conducted using TOP 02-2-718[44] as a guide. Vehicle ride dynamics tests should be conducted using TOP 01-1-014A CN1[45] as the guide.

4.2.10 Off-road Mobility.

a. The contribution of tires to the off-road mobility of a vehicle is significant. Bead slip, bead unseating and traction characteristics are covered in paragraphs 4.2.3, 4.2.4, and 4.2.6, respectively. The ability of a vehicle to traverse areas of low soil strength is impacted by the traction and the floatation. The mobility index (MI) was developed to address the overall vehicle trafficability. The MI is a dimensionless number obtained by applying specific vehicle characteristics and attributes using the following formula. Correlation of the MI to VCI has been established by rigorous field testing/experimentation. It is an excellent analytical method to compare the effects of tire type and inflation pressure to vehicle mobility. The MI relationship is presented below.

$$MI = [(CPF)(WF)/(TEF)(GF) + WLF - CF](EF)(TF)$$

$CPF = w/0.5ndb$
$TEF = 10+b/100$
$WLF = w/2000$
$CF = h_c/10$
$GF = 1 + 0.05c_{GF}$, $c_{GF} = 1$ if tire chains are used or 0 if not
$EF = 1 + 0.05c_{EF}$, $c_{EF} = 1$ if power-to-weight ratio < 10 Hp/ton or 0 if not
$TF = 1 + 0.05c_{TF}$ $c_{TF} = 1$ if a manual transmission or 0 if automatic

$WF = c_{WF1}(w/1000) + c_{WF2}$,
where,

$w < 2000$ lb	$c_{WF1} = 0.553$ and $c_{WF2} = 0$
$2000 \leq w < 13500$ lb	$c_{WF1} = 0.033$ and $c_{WF2} = 1.050$
$13500 \leq w < 20000$ lb	$c_{WF1} = 0.142$ and $c_{WF2} = -0.420$
$20000 \leq w < 31500$ lb	$c_{WF1} = 0.278$ and $c_{WF2} = -3.115$
$31500 \leq w$	$c_{WF1} = 0.836$ and $c_{WF2} = -20.686$

b. The nomenclature and units of measure used in the MI calculation is presented in Table 6.

TABLE 6. MOBILITY INDEX NOMENCLATURE

VARIABLE	DESCRIPTION
b	Average tire section width, inflated and unloaded, in.
CF	Clearance factor, dimensionless
CPF	Contact pressure factor, dimensionless
d	Average tire diameter, inflated and unloaded, in.
DCF	Deflection correction factor, dimensionless
EF	Engine factor, dimensionless
GF	Grouser factor, dimensionless
h	Average tire section height, inflated and unloaded, in.
h_c	Minimum ground clearance, in.

TABLE 6. CONTINUED

VARIABLE	DESCRIPTION
n	Number of tires per axle
TEF	Traction element factor, dimensionless
TF	Transmission factor, dimensionless
w	Average axle loading, lb
WF	Weight factor, dimensionless
WLF	Wheel load factor, dimensionless
δ	Average hard surface tire deflection, in.

c. Tire deflection was not considered in the early North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM) development and most of the tires used in military applications had tire deflections less than 15 percent of the tire section height. With central tire inflation systems and radial tire use commonplace on military vehicles, tire deflection can be considerably more than 15 percent and the U.S. Army Engineering Research and Development Center (ERDC) developed a Deflection Correction Factor (DCF) to account for tire deflection effects on the vehicle cone index. The DCF is represented by the following equation.

$$DCF = [0.15/(\delta/h)]^{0.25}$$

d. The deflection correction factor tends to normalize VCI to a performance magnitude at 15 percent tire deflection and is multiplied to the original equations empirically developed to predict the vehicle cone index (VCI) as a function of mobility index (MI). Significant field experimentation, mobility research, and methodology were used to generate these relationships over a variety of vehicles. The formulae are presented below based on the mobility index value. Statistical error and confidence in this method were verified and presented in ERDC literature[46].

e. The Vehicle Cone Index, single pass, is a function of the following.

$$VCI_1 = f(MI,DCF)$$

where, $MI \leq 115$ $\quad VCI_1 = [11.48 + 0.2MI - 39.2/(MI + 3.74)] * DCF$

$MI > 115$ $\quad VCI_1 = (4.1MI^{0.446}) * DCF$

f. The ability for a vehicle to cross marginal terrain may require demonstration in a variety of soil types and conditions. Tests can be as simple as a “go/no-go” where the vehicle configuration, soil type, and conditions are quantified. Video coverage and “before and after” site measurements (rut depth) are the minimum requirements. Additional instrumentation can be added to provide additional insight and increased analysis capability.

g. Note that vehicle sinkage and rut depth are not the same. Sinkage is measured instantaneously as the vertical movement of the wheel hub; rut depth is measured after traffic as the maximum vertical difference between the wheel rut profile and the original soil surface. Fine-grained soils often "rebound" slightly immediately after a wheel pass, and both fine- and coarse-grained soils often "fill in" a rut to some degree immediately after wheeled vehicle traffic.

These two types of actions both contribute to sinkage at least equaling, and often slightly exceeding rut depth. Thus, numeric predictions of sinkage should be slightly conservative for predicting rut depth.

4.2.11 Residual Mobility (Degraded Performance).

Tests are performed to analyze the loss of performance from vehicle damage incurred during live fire/vulnerability testing. Additional vehicle damage is often encountered over and above tires and wheels. Performance attributes are presented as a reduction of the base vehicle performance. Typical tests/metrics include:

a. VCI_1 (Vehicle Cone Index, single pass) performance.

b. Acceleration and maximum speed (TOP 02-2-602 CN1[47]).

c. Gradeability (True road speed on longitudinal grades, TOP 02-2-610[48]).

d. Obstacle negotiation (Steps and ditches, TOP 02-2-611[49]).

e. Steering performance (Munson standard steering course, TOP 02-2-718).

f. Drawbar pull (TOP 02-2-604).

4.2.12 Mechanical Reliability (Off-road Durability).

Testing is performed to determine a tire/wheel/runflat's ability to withstand sustained operation on severe off-road conditions, and is done in accordance with SAE J2014, sections 4.4.7 and A4[22].

4.2.13 Load and Pressure Adjustment.

a. The Tire and Rim Association permits tire load increases, often with increased inflation pressure, for Truck, Bus and Light Truck tires used on improved surfaces at reduced operating speeds. Rim and wheel manufacturers mark their products with a maximum load and inflation. This applies regardless of operating speed. The rim/wheel manufacturer must be contacted to determine if any deviation is permitted in the marked maximum load and inflation capacity of the rim or wheel at the operating condition in question.

b. Tire loading, vehicle speed, and inflation pressure scenarios falling outside the tire sidewall limits should be tested for endurance (see paragraph 4.1.6). Tire loading percentages should be calculated using the overloaded tire loading. The highest sustained vehicle speed expected should be used in lieu of the load range based speed presented in paragraph 4.1.6 or FMVSS 119. Operating tire pressures that are significantly higher or lower than the maximum tire pressure should be used.

5. PRESENTATION OF DATA.

5.1 General.

Individual test procedures referenced in this TOP should be reviewed and followed carefully. Data requirements, test controls and conditions, data analysis, and presentation should be followed. The tire and vehicle attributes used to determine tire performance are a combination of data determined by inspection and measurement. Tire component definitions are varied so care should be exercised when using specific definitions. Test procedures and/or standards should be cited in the reporting phase. Appendix A of this TOP provides some of the more commonly used definitions.

5.2 Data Presentation/Radar Plot.

Tire selection is never based on a single durability or performance metric. The best method to present the conclusions from individual tire tests/tire data is with a radar or spider plot. An example plot is shown in Figure 14. The radar plot visually shows in a single graphic the differences between the control and candidate tires. It clearly displays the important metrics being considered for analysis and defines full/acceptable performance in each category. The outward direction of each axis indicates either a percentage change or a difference compared to the reference tire. The red line indicates the nominal value for the reference tire.

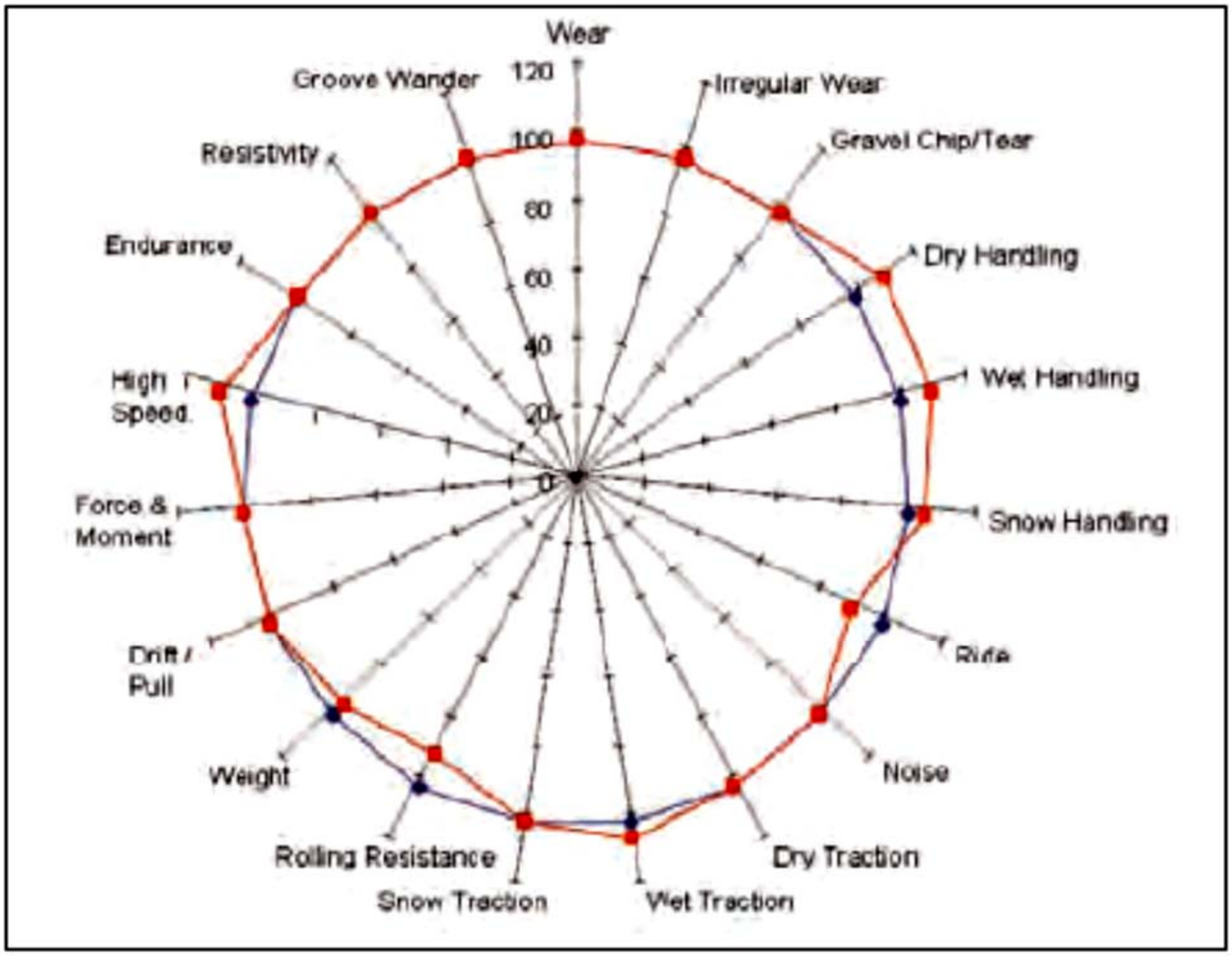

Figure 14. Radar (Spider) plot of tire performance.

APPENDIX A. GLOSSARY.

Term	Definition
Aspect ratio	Ratio of section height to section width of a tire times 100.
Bead	A circumferentially stiff ring of material wrapped or reinforced by tire cords and shaped to fit the rim. The bead anchors the body cords of the tire to the rim so that they can resist external and internal (pneumatic) forces.
Bead base	The inner portion of the bead that is seated on the bead seat.
Bead bundle	A circumferentially stiff hoop usually made of steel wires embedded in the bead that resists the inflation pressure generated forces.
Bead filler (apex)	A rubber compound fillet between the bead bundle and adjacent ply cords.
Bead heel	The outer edge of bead base.
Bead lock	A device mounted in the tire that fits between the beads to prevent bead unseating and tire rotation on the rim.
Bead spacer	A device mounted inside the tire that fits between the beads to prevent bead unseating, but does not prevent tire rotation on the rim.
Bead seat	The part of the rim that provides radial support to the tire.
Bead toe	The inner edge of bead base.
Belt separation	A breakdown of bonding between the belts and/or plies or tread.
Belt	An assembly of one or more pairs of stabilizer plies with their cords usually running at alternate angles.
Bias belted tire	Pneumatic tire structure of diagonal (bias ply) type in which the carcass is restricted by a belt comprising two or more layers of substantially inextensible cord material laid at alternate angles close to those of the carcass.
Blister	A separation within sidewall or liner stock or a separation between sidewall carcass or liner and carcass.

APPENDIX A. GLOSSARY.

Term	Definition
Bolt circle	A circle locating the centers of the bolt holes that are used to attach the wheel to the hub.
Bolt together divided wheel	A wheel that has a removable wheel portion that is attached to the fixed wheel portion by wheel clamp bolts and nuts.
Breaker	Ply (or plies) in a diagonal tire extending from tread shoulder to tread shoulder.
Cap ply	A stabilizer ply applied on top of the belt to improve belt performance at high speeds.
Carcass	The rubber-bonded cord structure of a tire (anchored to the bead) that contains the inflation-pressure generated forces.
Carcass ply	The ply extending from bead to bead.
Chafer (rim strip; clinch strip)	A layer of rubber compound, with or without fabric reinforcement, applied to the bead for resisting external damage.
Cone index	An index of the shearing resistance of a medium obtained with a cone penetrometer.
Contact length	The distance between the extreme points of the leading and trailing edge of the footprint measured parallel to the wheel plane of the straight free-rolling wheel.
Control tire	Tire used as a reference in a controlled test involving a group of tires.
Contact width	The distance between the extreme edges of the footprint measured in the plane perpendicular to the wheel plane of the straight free-rolling wheel.
Cord	A filamentary assembly formed by twisting together spun strands of textile or non-textile filaments, for reinforcing various tire components.
Cracking	Any parting within the tread, sidewall, or innerliner of the tire extending to cord material.

APPENDIX A. GLOSSARY.

Term	Definition
Cross-country	Vehicle operations over terrain not subject to repeated traffic and where no roads, routes, well-worn trails, or man-made improvements exist. (This definition does not apply to vehicle test courses that are used to simulate cross-country terrain.)
Deflection	The difference between the unloaded and the loaded section heights.
Diagonal tire (bias tire, cross ply tire)	Pneumatic tire in which the ply cords extend to the beads and are laid at alternate angles substantially less than 90 degrees to the centerline of the tread.
DOT code	Letters and numbers molded or branded into or onto the sidewall of tire designated for use on highways containing codes for manufacturer, size, type (optional), date of manufacture of the tire, and the symbol identifying the country of origin (for example, DOT is the acronym for U.S. Department of Transportation). Example: UDXXXXX409 where UD denotes plant number, XXXXX company code, and 409 manufacturing date (the 40th week of 1989).
Dual tires	Two similar tires mounted side-by-side at the same axle end.
Element (lug, block)	A discontinuous tread projection.
ETRTO	The European Tyre and Rim Technical Organisation.
Flange	The shaped portion of a rim that retains the outer edges of the beads.
Flap	Rubber strip that fits inside the tire to protect tube from pinching by the beads or rubbing on the rim. Normally used with tubeless tires.
Flotation	Ability of a tire to resist sinkage on soft, yielding terrain.
Footprint	The contact area of a tire loaded against a flat or curved surface.
Footprint aspect ratio	The tire footprint length divided by the tire footprint width times 100.

APPENDIX A. GLOSSARY.

Term	Definition
G-G ring	The raised circumferential rubber ring or guide rib on the tire sidewall above the rim flange used to gauge concentric tire mounting on the rim. It should not exceed 2/32 in. difference.
Grown tire	A tire that has undergone expansion due to use in service and past inflation.
Groove	An essentially continuous channel molded or cut into the tread rubber. Kerfs and cuts are not included.
Gutter	A groove at one edge of a rim where the lock ring or side ring fits.
Heel	The rounded portion of the bead fitting at the junction of the rim flange and the bead seat.
Heel and toe wear	A type of irregular tread wear characterized by different wear rates at the leading and trailing edges of a tread element.
Highway	Four or more lanes, often divided, all-weather primary roads used for heavy and high density traffic usually with a limited access to/from other roads.
Innerliner	A low air diffusion layer covering the inside of the carcass of a tubeless tire.
Innerliner separation	The parting of the innerliner from cord material in the carcass.
Inner tube	A low-diffusion hollow section rubber torus which retains compressed air within a tube-type tire and thus allows maintenance of a pre-stressed state in the tire structure.
Juncture	The interface between two different tire components, or different compounds (materials) within the same components.
Load index	A numerical code associated with the maximum load a tire can carry at the speed indicated by its speed symbol under specified service conditions.

APPENDIX A. GLOSSARY.

Term	Definition
Load range	The term "load range" with a letter (A, B, C, etc.) in tire identification is used to identify a given size tire with its load and inflation limits when used in a specific type of service, as defined in the heading of TRA tables.
Maximum tire/wheel load rating	The maximum load a tire is rated to carry at a specified maximum speed and operating condition. The maximum load rating of the wheel should also be considered when determining the maximum load rating of a tire and wheel system.
Notch	A slot with a closed end, wider than a sipe, but in most cases, narrower than a groove.
Nominal contact area	The area of the footprint as described by the size and shape of the footprint including grooves and voids in the tread pattern.
Off-road/off-highway	These terms are synonymous, with off-road being preferred. Vehicle operations over trails or cross-country.
Off-the-road tires	Tires designed primarily for use over unpaved roads or where no roads exist. Built for ruggedness and traction rather than speed.
On-road/on-highway	These terms are synonymous, with on-road being preferred. Vehicle operation over prepared road surfaces, to include highways, primary roads, and secondary roads.
Overall width	The width of an unloaded new tire inflated to recommended pressure 24 hours prior to measurement thus taking account of inflation growth. Protective ribs, bars, and decorations are included.
Overloading	Loads over and above the maximum load limits for speed, tire size, inflation pressure, and operating conditions. The tire load capacity can be increased in certain cases by increased inflation or control to lower speeds.
Percent carcass deflection	Deflection is the difference between the unloaded and the loaded section heights. This term must is used in the VCI calculations.
Percent tire deflection	Deflection is the difference between the unloaded and the loaded section heights. This is a TRA and commercial industry term and must not be used for VCI calculations.

APPENDIX A. GLOSSARY.

Term	Definition
Ply	A sheet of rubber-coated cords.
Ply turn-up	The portion of the ply passed around the bead bundle.
Pneumatic tire	A flexible, hollow semi-toroid mounted on the rim and filled with compressed gas (usually air) to attenuate road impact forces and produce vehicle control forces.
Primary Roads	Two or more lanes, all weather, maintained, hard surfaced (paved) roads with good driving visibility used for heavy and high-density traffic. These roads have lanes with a minimum width of 9 ft, and the legal maximum Gross Vehicle Weight/Gross Combined Weight (GVW/GCW) for the country or state is assured for all bridging.
Radial ply tire	A pneumatic tire in which the ply cords extend to the beads and are laid substantially at 90 degrees to the centerline of the tread, the carcass being stabilized by an essentially inextensible circumferential belt.
Reversion	Excessive heating of a cured rubber compound leading to deterioration of its physical properties.
Rib	An essentially continuous, circumferential tread projection.
Rim	That part of the wheel on which the tire is mounted and supported.
Rim base	Portion of a rim remaining after removal of all split or continuous rim flanges, side rings, and locking rings that can be detached from the rim.
Rim diameter designation (nominal rim diameter)	The nominal rim diameter assigned for tire/rim matching.
Rim size designation	Rim diameter designation x rim contour designation. Example: 15 x 6 J, which denotes a 15 inch nominal rim diameter, 6 inch nominal rim width, and J rim profile.
Rim width	Distance between the inside surfaces of the rim flanges.
RMA	Rubber Manufacturers Association.

APPENDIX A. GLOSSARY.

Term	Definition
Rolling radius	Vertical distance from the axle horizontal centerline to the road under any given condition of load, speed, and inflation.
Row	A sequence of tread elements along a circumferential line.
Runflat device	A structural insert for a pneumatic tire designed to carry the load for a limited distance if the tire is deflated.
Section height	The height of radial cross section of a tire including 24-hour inflation growth, usually calculated as half the difference between the tire overall diameter and the nominal rim diameter.
Section width	The width of an unloaded, new tire inflated to the recommended pressure 24 hours prior to measurement thus taking account of inflation growth (see, for example, the T&RA Year Book). Protective ribs, bars, and decorations are excluded.
Secondary road	Two lanes, all weather, occasionally maintained hard or loose surfaced (for example, large rock, paved, crushed rock, gravel) roads intended for medium weight, low-density traffic. These roads have lanes with minimum width of 8 ft and no guarantee that the legal maximum GVW/GCW for the country or state is assured for all bridges.
Service description (load/speed index)	A code consisting of load index and speed symbol, which is not part of the tire size designation. Example: 90 H.
Shoulder rib	A rib at the outer edge or shoulder of the tread band.
Shoulder row	A row located at or near the shoulder of the tread band.
Sidewall	The portion of the tire between the bead and the tread.
Sidewall rubber	The layer of rubber compound on the outside of the sidewall; it may include ornamental or protective ribs.
Sidewall separation	Sidewall separation means the parting of the rubber compound from the cord material in the sidewall.
Sipe	A narrow slot usually less than 1 mm wide.

APPENDIX A. GLOSSARY.

Term	Definition
Slip angle	The angular displacement of the tire centerline and direction of travel.
Specific contact area	The area of the footprint as described by the size and shape of the footprint excluding grooves and voids in the tread pattern.
Speed symbol	A symbol indicating the speed category at which the tire can carry a load corresponding to its load index under specified service conditions.
Speed rating	Maximum speed that the tire is rated by the manufacturer for a specific operation.
Split rim	Rim divided circumferentially into two or more sections.
Static loaded radius	Vertical distance from the axle horizontal centerline to the road under any given condition of load and inflation while stationary.
TRA	Tire and Rim Association.
Tread	The portion of the tire that comes in contact with the road.
Tread rib	A tread section running circumferentially around a tire.
Tread depth	The distance in 32nds of an inch measured from the tread surface to the bottom of the grooves in a tire.
Tread pattern	The molded geometric configuration on the peripheral tread face, generally composed of tread projections and voids.
Tread projection	Raised portions of the tread pattern, contacting the road surface when passing through the footprint.
Tread separation	Tread pulling away from body of tire.
Tread shoulder	The outermost portion of the tread adjacent to the sidewall.
Tread wear indicator (wear bar)	Raised bottom portions of a groove or void, spaced regularly around the tire across the tread to provide a visual indication of wear-out.
Tread width	The distance from shoulder to shoulder of a tire.

APPENDIX A. GLOSSARY.

Term	Definition
Tube-type tire	A pneumatic tire which requires an inner tube for air retention.
Tubeless tire	A pneumatic tire which does not require an inner tube, inflation pressure is retained by the tire inner liner, the rim, and the valve.
Underinflation	Tire having less than recommended air pressure for the specific load, speed, and terrain conditions.
Undertread	Tread material between bottom of tread grooves and carcass.
Vehicle Cone Index (VCI)	Minimum soil strength in the critical soil layer, in terms of rating cone index for fine grain soil (clay) or in cone index for coarse grain soils (sands), required for a single pass of a vehicle, VCI_1.
Void	An open space between tread elements or ribs. Groove (Void) Depth (Tread Depth) - The depth of a groove or void measured perpendicular to the reference plane defined by the edges of adjacent tread elements.
Weather side	Surface area of the rim not covered by the inflated tire.
Wheel	A rotating load-carrying member between the tire and the hub. It usually consists of two major parts: (a) the rim and (b) the wheel disc. The rim and wheel disc may be integral, permanently attached, or detachable.
Wheel clamp bolt	An externally threaded fastener which, when used with clamp nuts, serves to secure the removable wheel portion to the fixed wheel portion of a bolt together divided wheel.
Wheel clamp nut	An internally threaded fastener which, when used with clamp bolts, serves to secure the removable wheel portion of a bolt together divided wheel.

APPENDIX A. GLOSSARY.

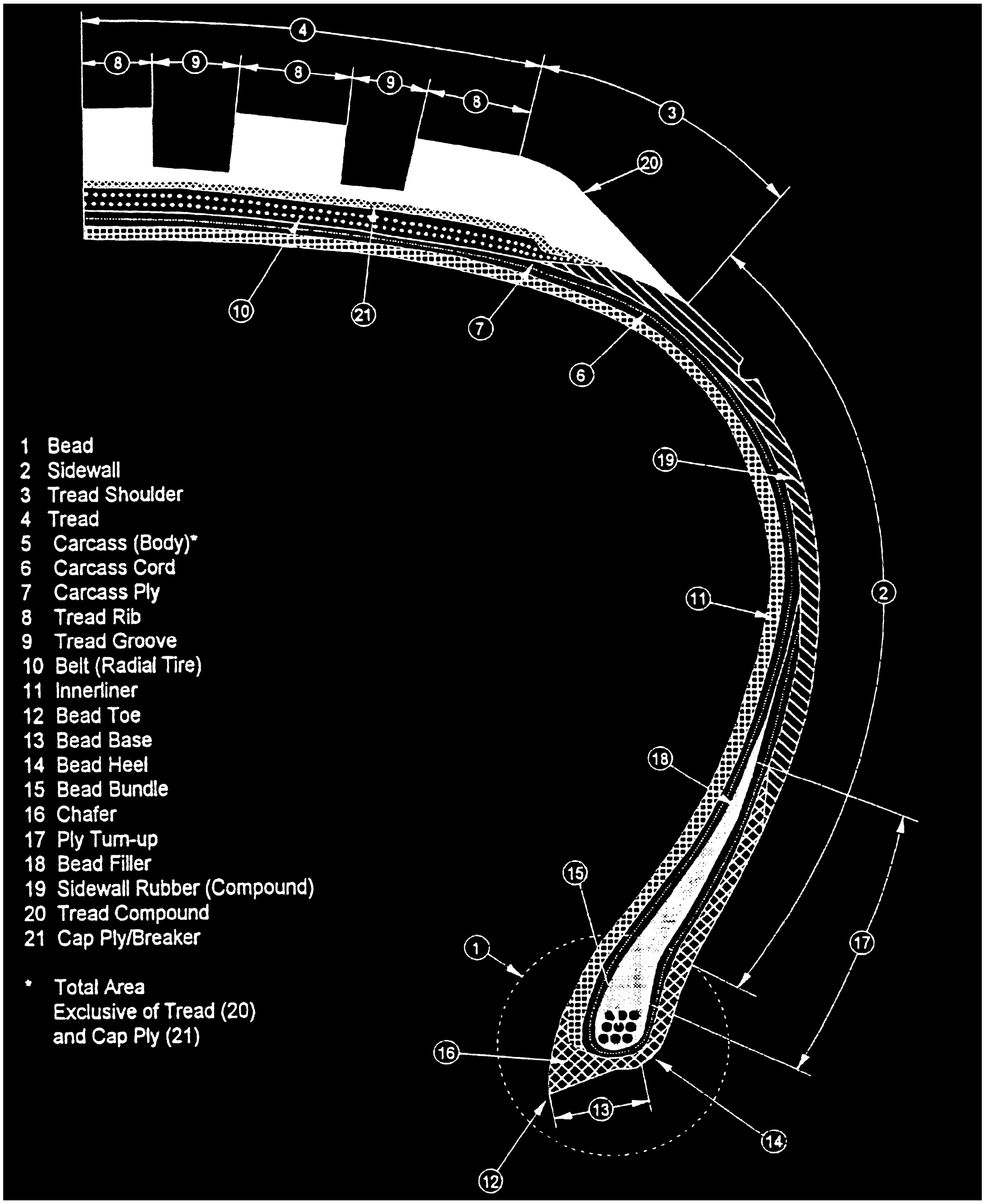

Figure A-1. Tire components and elements (SAE J2047).

APPENDIX B. ABBREVIATIONS.

AASHTO	American Association of State Highway and Transportation Officials
AEC	U.S. Army Evaluation Center
ASTM	American Society for Testing and Materials
ATC	U.S. Aberdeen Test Center
ATEC	U.S. Army Test and Evaluation Command
C	Celsius
CAN	Controller Area Network
CF	Clearance Factor (mobility index calculation)
CFR	Code of Federal Regulations
CI	cone index
cm	centimeter
CPF	Contact Pressure Factor (mobility index calculation)
CTIS	central tire inflation system
DCF	Deflection Correction Factor
DOT	Department of Transportation
EF	Engine Factor (mobility index calculation)
ERDC	U.S. Army Engineering Research and Development Center
ETRTO	European Tyre and Rim Technical Organization
F	Fahrenheit
ft	feet
FM	Field Manual
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
GCW	Gross Combined Weight
GF	Grouser Factor (mobility index calculation)
GVW	Gross Vehicle Weight
Hz	Hertz (frequency)
in.	inch
ISO	International Standards Organization
kg	kilogram
km/hr	kilometers per hour
kN	kilonewton
kPa	kilopascal

APPENDIX B. ABBREVIATIONS.

lb	pound
lbf	pounds force
LS	loaded section width
m	meter
MI	mobility index
mm	millimeter
mph	miles per hour
N	Newton
NATO	North Atlantic Treaty Organization
NCHRP	National Cooperative Highway Research program
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NRMM	NATO Reference Mobility Model
NSN	National Stock Number
NTE	not to exceed
OBSI	on-board sound intensity
pfc	peak friction coefficient
ppm	parts per million
psi	pounds per square inch
RTI	ramp travel index
RWS	Roadway Simulator
SAE	Society of Automotive Engineers
SBFA	Setback Front Axle
SM	silty-sand (from Unified Soil Classification System)
SP	poorly graded sand – uniform particle size
SR	Safety Release
SWIFT	Spinning Wheel Integrated Force Transducer
TEF	Traction Element Factor (mobility index calculation)
TF	Transmission Factor (mobility index calculation)
TIN	tire identification number
TM	Technical Manual
TMC	Truck Maintenance Council
TPMS	tire pressure monitoring system
TOP	Test Operations Procedure

APPENDIX B. ABBREVIATIONS.

TRA	Tire and Rim Association
TSARC	Test Schedule and Review Committee
TTR	tire test rig
USCS	Unified Soil Classification System
VCI	Vehicle Cone Index
VCI_1	Vehicle Cone Index, Single Pass
WF	Weight Factor (mobility index calculation)
WLF	Wheel Load Factor (mobility index calculation)

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APPENDIX C. REFERENCES.

1. Carriere, John A. and DeCarteret, David T., General Motors Corp., Vehicle Handling Parameter Trends: 1980 -2010, Society of Automotive Engineers (SAE) International, 2011.

2. FM 5-340, Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations: Volume 2, Airfield and Heliport Design, August 1987.

3. AASHTO T217-1986, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, 13th edition, 1986.

4. ASTM D2216-10, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, 1 July 2010.

5. ASTM Method E1337-90, Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using Standard Reference Test Tire, 2012.

6. Tire Storage Recommendations, Yokohama Technical Services Bulletin, Nov 21, 2002.

7. The Tire and Rim Association (TRA) Inc., 175 Montrose West Avenue, Suite 150, Copley, Ohio 44321. www.us-tra.org.

8. The European Tyre and Rim Technical Organisation (ETRTO), Rue Defacqz 78-80, B - 1060 Brussels, Belgium. www.etrto.org.

9. National Highway Traffic Safety Administration (NHTSA). www.nhtsa.dot.gov.

10. FM 21-305, Manual for the Wheeled Vehicle Driver, August 1993.

11. FMCSA Regulation Part 393.75: Tires, August 2005.

12. ASTM F1426 Standard Practice for Identifying Tire Tread Surface Irregular Wear Patterns Resulting from Tire Use, 2011.

13. Giapponi, Thomas, “Tire Forensic Investigation - Analyzing Tire Failure”, SAE International, 2008.

14. SAE International Surface Vehicle Information Report, J2047 Tire Performance Technology, February 1998.

15. Code of Federal Regulations (CFR), Title 49, Subtitle B, Chapter V, Section 571, FMVSS 120, Tire Selection and Rims for Motor Vehicles Other Than Passenger Cars, June 2007.

APPENDIX C. REFERENCES.

16. CFR, Title 49, Subtitle B, Chapter V, Section 571, FMVSS 119, New Pneumatic Tires for Motor Vehicles with a GVWR of more than 4,536 kilograms (10,000 pounds) and Motorcycles, October 2014.

17. SAE International Surface Vehicle Recommended Practice, Steady-State Circular Test Procedure for Trucks and Buses, SAE Standard J2181, September 2011.

18. SAE International Surface Vehicle Recommended Practice, Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques, SAE Standard J1263, March 2010.

19. SAE International Surface Vehicle Recommended Practice, Road Load Measurement Using Onboard Anemometry and Coastdown Techniques, SAE Standard J2263, December 2008.

20. SAE International Surface Vehicle Recommended Practice, Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance, SAE Standard J2452, August 2008.

21. SAE International Surface Vehicle Recommended Practice, Fuel Consumption In-Service Test Procedure Type III, SAE Standard J1526, April 2011.

22. SAE International Surface Vehicle Recommended Practice, Vehicle Acceleration Measurement, SAE Standard J1491, July 2006.

23. SAE, Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires, SAE Standard J1269, September 2006.

24. SAE International Surface Vehicle Standard, Pneumatic Tires for Military Tactical Wheeled Vehicles, SAE Standard J2014, June 2012.

25. SAE International Surface Vehicle Recommended Practice, Vehicle Dynamics Terminology, SAE Standard J670, January 2008.

26. SAE International Surface Vehicle Recommended Practice, Laboratory Testing Machines for Measuring the Steady State Force and Moment Properties of Passenger Car Tires, SAE Standard J1106, January 1975.

27. SAE International Surface Vehicle Information Report, J1107, Laboratory Testing Machines for Measuring the Steady State Force and Moment Properties of Passenger Car Tires, January 1975.

28. Cook, Michael, Test Record No. 13-VET(P)-02, ATEC Project No. 2013-DT-ATC-TIRES-F6247, July 2013.

APPENDIX C. REFERENCES.

29. TOP 02-2-801, Weight Distribution and Ground Pressure (Wheeled and Tracked Vehicles), 26 September 2006.

30. Lindemuth, B.E., The Pneumatic Tire; An Overview of Tire Technology, NHTSA, DOT HS-810 561, February 2006.

31. FMCSA study, Commercial Vehicle Tire Condition Sensors, November 2003).

32. TOP 02-2-506A, Wheeled and Tracked Vehicle Endurance Testing, 2 October 2014.

33. McNorton, Tom and Wheeler, Fred, Rockwell International and Michelin Americas Research and Development Corp., “Camber and Toe Effect on Setback Front Axle (SBFA) Heavy Truck Steering Axle Wear”, SAE Paper 922485, SAE International, 1992.

34. Miller, Gerald, Reed, Robert, and Wheeler, Fred, Michelin Americas Research and Development Corp., “Optimum Ackerman for Improved Steering Axle Wear on Trucks”, SAE Paper 912693, SAE International, 1991.

35. TOP 02-2-698, Runflat Testing, 9 September 2015.

36. Finabel Agreement No A.20.A, “Combat Tyres”, March 1997.

37. TOP 02-2-604, Drawbar Pull, 26 September 2007.

38. TOP 02-2-619, Soft-Soil Vehicle Mobility, 21 May 1970.

39. TOP 01-1-011A, Vehicle Test Facilities at Aberdeen Test Center and Yuma Test Center, 27 February 2012.

40. TOP 02-2-608, Braking, Wheeled Vehicles, 20 May 2008.

41. Transportation Research Board of the National Archives, National Cooperative Highway Research Program (NCHRP), Report 630, Measuring Tire Noise at the Source, 2009.

42. ISO 10844, Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tires, February 2011.

43. SAE International Surface Vehicle Recommended Practice, Subjective Rating Scale for Vehicle Handling, SAE Standard J1441, April 2007.

44. TOP 02-2-718, Electronic Stability Control, 5 December 2013.

APPENDIX C. REFERENCES.

45. TOP 01-1-014A Change Notice 1, Ride Dynamics and Evaluation of Human Exposure to Whole-Body Vibration, 3 April 2012.

46. Priddy, Jody D. and Willoughby, William E., Journal of Terramechanics, “Clarification of Vehicle Cone Index with Reference to Mean Maximum Pressure”, Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, 2006.

47. TOP 02-2-602 CN1, Acceleration; Maximum and Minimum Speeds, 28 January 1981.

48. TOP 02-2-610, Gradeability and Side Slope Performance, 3 December 2009.

49. TOP 02-2-611, Standard Obstacles, 17 March 2010.

APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 15 December 2015

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 02-2-704A Tires, Approved for Publication

1. TOP 02-2-704A Tires, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP describes the general procedures for testing pneumatic tires used on tactical wheeled vehicles. The procedures described apply to original equipment and new replacement tires. This document also describes vehicle and component level tests that will be used to measure and analyze tire and vehicle related performance. The mission profile of the vehicle helps determine which of these tests are required and should be selected.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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Date: 2015.12.17

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data that may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Directorate (TEDT-AT-AD), U.S. Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.